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CRYOFRACTURE DEMILITARIZATION OF MUNITIONS (PHASE II)

John F. Follin
General Atomics
P.O. box 85608
San Diego, CA 92186-9784

Andrew Lute
Project Engineer
TACOM-ARDEC

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John F. Follin, General Atomics
Andrew Lute, Project Engineer, ARDEC

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General Atomics
P.O. Box 85608
San Diego, CA 92186-9784

ARDEC, WECAC
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(AMSTA-AR-WEA)
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14. ABSTRACT
The U.S. Army has mission responsibility for carrying out the demilitarization of obsolete conventional munitions currently in the stockpile. In support of this activity, efforts are underway to develop technologies that will accomplish the demilitarization in a safe and environmentally friendly manner. The use of cryofracture to accomplish the task for small explosive loaded munitions is one of the technologies being developed.

This report details the results of the second phase of testing conducted at Dugway Proving Ground. In this phase, area denial artillery munition (ADAM) mines, Rockeye II MK 118 antitank bomblets, M16 series antipersonnel landmines, and inert M483A1 projectiles were processed to expand the envelope of application of cryofracture as a demilitarization technology. Prior to conducting tests using live munitions, inert versions were used to establish parameters such as munition cool-down time and crush height of the press and verify the repeatability of the press tooling configuration to perform as intended. Data obtained from these tests, as well as the Phase I tests, are serving as the basis for the development of a prototype cryofracture demilitarization facility to be located at McAlester Army Ammunition Plant, McAlester, OK.

15. SUBJECT TERMS
Demilitarization, Cryofracture, Liquid nitrogen, ADAM, Rockeye II, Bomblets, Munitions, Destruction, Mines

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INTRODUCTION

Cryofracture involves the cooling of the munitions in a liquid nitrogen bath, followed by fracture of the embrittled item(s) in a hydraulic press and the subsequent thermal treatment of the fractured munition debris in order to destroy the explosives and decontaminate any residual metal parts (which may be recovered for scrap value). Because cryofractured debris burns rather than detonates, cryofracture significantly increases the rate at which items such as grenades or mines can be demilitarized by eliminating item detonation that sometimes occurs when they are subjected to a thermal destruction process. Thus, in addition to increasing throughput, reduced hazard to both the equipment and personnel during thermal destruction is an inherent benefit of the cryofracture process. Process development and testing to date has been conducted at the Munitions Cryofracture Test Facility (MCTF) located on the West Desert Test Center (WDTC) site at Dugway Proving Ground (DPG) in Utah. Testing was conducted on four types of munitions in order to establish cryofracture process parameters such as munition cool down time, press tooling configuration, and press closure; provide confidence that the process could be carried out in a safe, repeatable manner; and develop data for the design of a prototype production cryofracture demilitarization facility. Items tested included inert M483A1 projectiles with 88 M42/M46 inert bomblets, Rockeye II MK 118 antitank bomblets (21 inert, 247 live), M16 antipersonnel landmines (4 inert, 61 live), and the Area Denial Artillery Munition (ADAM) mines (36 inert, 100 live QA, 360 live AP). The ADAM QA mines are similar to the ADAM antipersonnel (AP) mines except the QA mines do not contain live overlay/kill mechanisms (O/KMs). The ADAM mine required additional post-cryofracture steps which included debris separation, debris deactivation by induction heating, and further accessing of O/KMs containing Comp A5 explosive by a second small press. The results of the testing have overwhelmingly demonstrated the value of the process and its maturity for implementation in a Munitions Cryofracture Demilitarization Facility (MCDF) to be located at the McAlester Army Ammunition Plant (MCAAP).

During initial development of the cryofracture process for the chemical demilitarization test program (1990 to 1993), a number of tests involving handling and cryofracture of explosively configured munitions were conducted at the MCTF at DPG. The purpose of these tests was to demonstrate the feasibility of the cryofracture process for chemical munitions. These tests successfully demonstrated that explosively configured, agent simulant filled munitions could be handled, cryocooled, and cryofractured without explosive events.

The first phase of tests involving handling and cryofracture of explosively configured conventional munitions were conducted at the MCTF at DPG in 1995 (ref. 1). The purpose of these tests was to demonstrate the feasibility of the cryofracture process for small-bodied hard-to-disassemble conventional munitions. These tests also successfully demonstrated that explosively configured, small munitions could be handled, cryocooled, and cryofractured without explosive events. In total, over 4900 explosively configured munitions were successfully cryofractured at the DPG site. Table 1 summarizes the type and quantity of munitions cryofractured along with the packaging for each munition type.

Table 1
Munitions previously cryofractured

Munition type	Packaging	No. of munitions cryofractured
155-mm projectile	Bare, burstered	1204
105-mm cartridge	2 in wood box, fuzed & burstered	70
105-mm projectile	Bare, fuzed & burstered, fractured 2 at-a time	1624
4.2-in. mortar	2 in wood box, fuzed & burstered	98
4.2-in. mortar	Bare, fuzed, fractured 2 at-a-time	400
Land mine	3 in metal drum with fuzes, initiators, & bursters	99
115-mm rocket	1 in firing tube, fuzed & burstered	200
M77 submunition grenade	Single batch cryofracture	433
M67 hand grenade	Single batch cryofracture	330
M61 hand grenade	Single batch cryofracture	321

The purpose of the latest series of tests as documented in this report was to use the MCTF to demonstrate the feasibility of the cryofracture process for conventional munitions, with emphasis on munitions that are difficult to disassemble such as the ADAM mine. Additionally, the results (munition cool down, press tool set design, transport fixture design, deactivation parameters, etc.) will be incorporated into the MCAAP MCDF final design. A test plan (ref. 2) and a safety assessment/ preliminary hazard analysis (ref. 3) were prepared to establish a basis for all testing.

SUMMARY OF TESTING

ADAM Mines

A series of 11 cryofractures of inert (previously functioned ADAM QA mines from Yuma Proving Ground) mines were performed to establish the parameters to be used in subsequent live ADAM mine cryofractures. A total of 36 inert mines were cryofractured.

A total of 21 cryofractures of live ADAM QA mines were then successfully performed to demonstrate the feasibility of the cryofracture process and the debris separation/deactivation for this munition. The ADAM QA mines are similar to the ADAM AP mines except the QA mines do not contain live O/KMs. Two series of tests were performed. Tests 1 through 12 used a vibratory tube conveyor to transport the cryofractured mine housing debris containing small energetics through an induction heating coil for deactivation. Tests 13 through 21 used a screw conveyor to transport the material through the induction coil. The screw conveyor was judged to be superior to the vibratory tube conveyor. A total of 100 ADAM QA mines were processed with no upsets during cryocooling, robotic handling, fracture, discharge, or deactivation operations.

A total of 64 cryofractures of live ADAM AP mines (up to six at a time) were then successfully performed to demonstrate, in addition to the previous operational steps, the feasibility of the punch out of the O/KM and the subsequent accessing by a small press and incineration of the O/KM. Tests 1 through 38 used a flat-plate upper and lower tool set in the O/KM accessing press prior to incineration. A O/KM detonated during test 39. After replacing the flat-plate tooling in the accessing press with a scalloped lower plate, tests 40 through 64 were run with no further problems. A total of 360 ADAM AP mines were processed. These tests demonstrated the following:

- Short cool down time. Acceptable cool down duration as low as 10 min. was demonstrated.
- Reasonable margin for out-of cryobath warm-up time prior to fracture. Warm-up time of up to 2 min. was demonstrated.
- Reasonable transport fixture arrangement for multiple mine fractures.
- The ability of the robot using reusable transport fixtures to accurately place the munitions on the press tooling.
- The ability of the press to cryofracture up to six mines in a single fracture.
- Good O/KM punch out and mine housing brittle fracture.
- Good O/KM explosive accessing.
- The ability to access six O/KMs at a time.
- Good mine housing small energetic deactivation.
- The ability of the induction heating system with a gaseous nitrogen purge to minimize the burning of epoxy.
- Good punch/separation methods to minimize the amount of epoxy that was incinerated.
- The ability to recover gold and other precious metals from the deactivated waste and mine housing debris.

The parameters determined by testing for the cryofracture of ADAM mines were as follows:

- Cool down time – 10 min.
- ADAM Mine flat plate press closure spacing – 0.75 in.
- Mine spacing – minimum center-to-center distance – 6 in.
- O/KM accessing crush distance – 0.37 in.

- Small energetic deactivation residence time – 58 sec

- Approximate percentage by weight of epoxy fed to the incinerator along with O/KMs – 3.36%

Rockeye II MK 118 AT Bomblets

A series of 11 cryofractures of inert Rockeye II MK 118 AT bomblets were performed to establish the parameters to be used in subsequent live AT bomblet cryofractures. A total of 14 bomblets were cryofractured.

A series of 37 cryofractures of live Rockeye II MK 118 AT bomblets (up to seven at a time) successfully demonstrated the feasibility of the cryofracture process for this munition. A total of 247 bomblets were processed with no explosions during cryocooling, robotic handling, or fracture operations. The detonator from each bomblet usually initiated during debris burning in the open gate furnace, but the primary charge did not. These tests demonstrated the following:

- Good brittle fracture and explosive accessing.

- Short cool down time. Acceptable cool down duration as low as 10 min. was demonstrated.

- Reasonable margin for out-of cryobath warm-up time prior to fracture. Warm-up time of up to 2 min. was demonstrated.

- Reasonable transport fixture arrangement for multiple bomblet fractures.

- The ability of the press to cryofracture up to seven bomblets in a single fracture.

- The ability of the robot using reusable transport fixtures to accurately place the munitions on the press tooling.

The parameters determined by testing for the cryofracture of Rockeye II MK 118 AT bomblets were as follows:

- Cool down time – 10 min.

- Press closure spacing – 1.5 in.

- Bomblet spacing – 3-in. side-to-side

M16 AP Mines

A series of six cryofracture tests was performed on inert M16 AP mines. Testing with the M16 AP mines in both horizontal and vertical orientation were performed. The test results showed that the crushing of vertically oriented mines provided excellent breakup of the metal components and also excellent accessing of the explosive cavities. A total of four mines were cryofractured.

A series of 25 cryofractures of live M16 AP mines (up to three at a time) successfully demonstrated the feasibility of the cryofracture process for this munition. A total of 61 mines were processed with no explosions during cryocooling, robotic handling, or fracture operations. The detonator from each mine usually initiated during debris burning in the open gate furnace, but the primary charge did not. These tests demonstrated the following:

- Good brittle fractures and explosive accessing.
- Acceptable cool down duration as low as 30 min. was demonstrated with or without fuze plugs inserted in the mine fuze cavity.
- Reasonable margin for out-of cryobath warm-up time prior to fracture. Warm-up time of up to 2 min. was demonstrated.
- Reasonable transport fixture arrangement for multiple mine fractures.
- The ability of the press to cryofracture up to three mines in a single fracture.
- The ability of the robot using reusable transport fixtures to accurately place the munitions on the press tooling.

The parameters determined by testing for the cryofracture of M16 AP mines were as follows:

- Cool down time – 30 min.
- Press closure spacing – 3.25 in.
- Minimum mine spacing (vertical center line spacing) – 7.5 in.

Inert M483A1 155-mm Projectiles

A series of 11 cryofractures was performed on inert M483A1 projectiles and segments of projectiles. Two press tooling configurations were used in an effort to not only break up the projectile body, but also to fracture the M42 and M46 submunition grenades contained within the projectile body and to access the expulsion charge cavity in the nose of the projectile. The first tool set was shaped to closely confine the projectile body and submunition grenades following the fracture. The second tool set was comprised of upper and lower flat plates. The results of the tests showed that, within the 750 ton capacity of the test facility press, neither tool set provided the necessary breakup of the projectile body and all of the submunition grenades.

TEST FACILITY DESCRIPTION

The munitions cryofracture test facility is located on the WDTC at DPG in Utah. The vicinity map in figure 1 locates DPG relative to Salt Lake City. Figure 2 shows details of DPG along with the location of the munitions cryofracture test site. Layouts showing the arrangement of major equipment items for the test facility are shown in figures 3 through 5.

The major piece of equipment, around which the other equipment is located, is a hydraulic press. A munitions handling robot is located adjacent to the press and a track-mounted cryobath is located adjacent to the robot. The cryobath moves on its track to permit the robot to reach all locations in the bath.

The facility was constructed in 1990 for the test program for chemical demilitarization. Equipment changes made to the facility in 1998 to accommodate the ADAM mine testing included reusable transport fixtures, debris separation equipment, separate O/KM accessing, induction heating for debris deactivation, shuttle box conveyance for open grate incineration, and control system upgrades.

All live munitions handling operations relative to moving the munitions into or out of the cryobath, the press, the open grate furnace, and other energetic processing equipment, are designed to be performed remotely. Test operations (for live munitions) are controlled by personnel in a remotely located control station. Closed circuit television (CCTV) cameras installed at key positions provide test personnel with visual confirmation that the critical steps in the test operation are performed successfully. A supervisory computer monitors and controls all mechanical components and collects all required data.

All inert munitions except for the Yuma ADAM QA mines (previously functioned) were manually loaded into the cryobath, removed from the cryobath, and placed in the press tooling. The Yuma ADAM QA mines and all explosively configured munitions were manually placed in reusable munition transport fixtures positioned on the cryobath loading platform. All subsequent explosively configured munitions handling operations were performed remotely with no personnel in the test facility building.

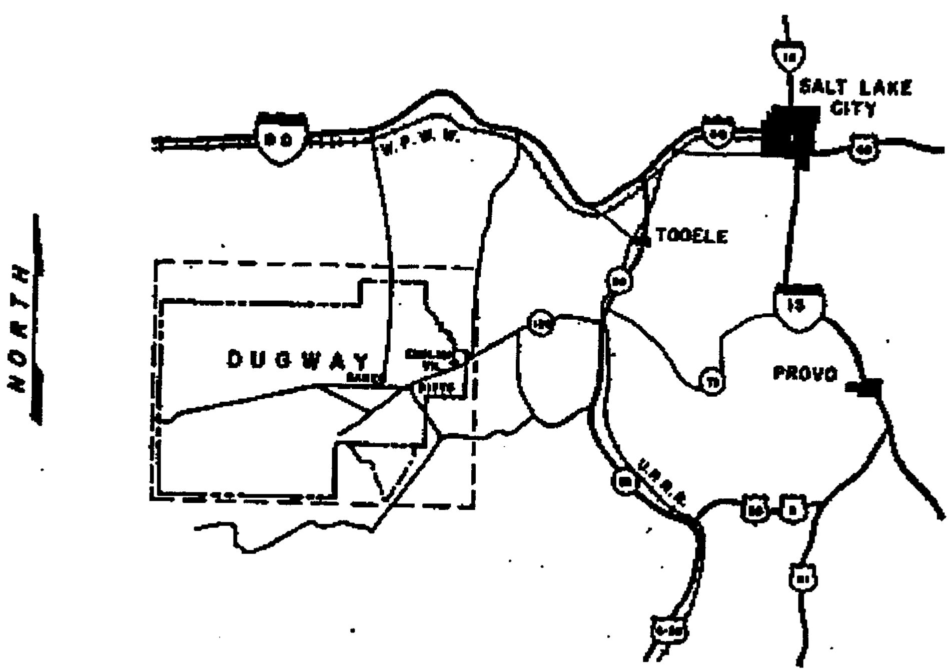


Figure 1
Vicinity map

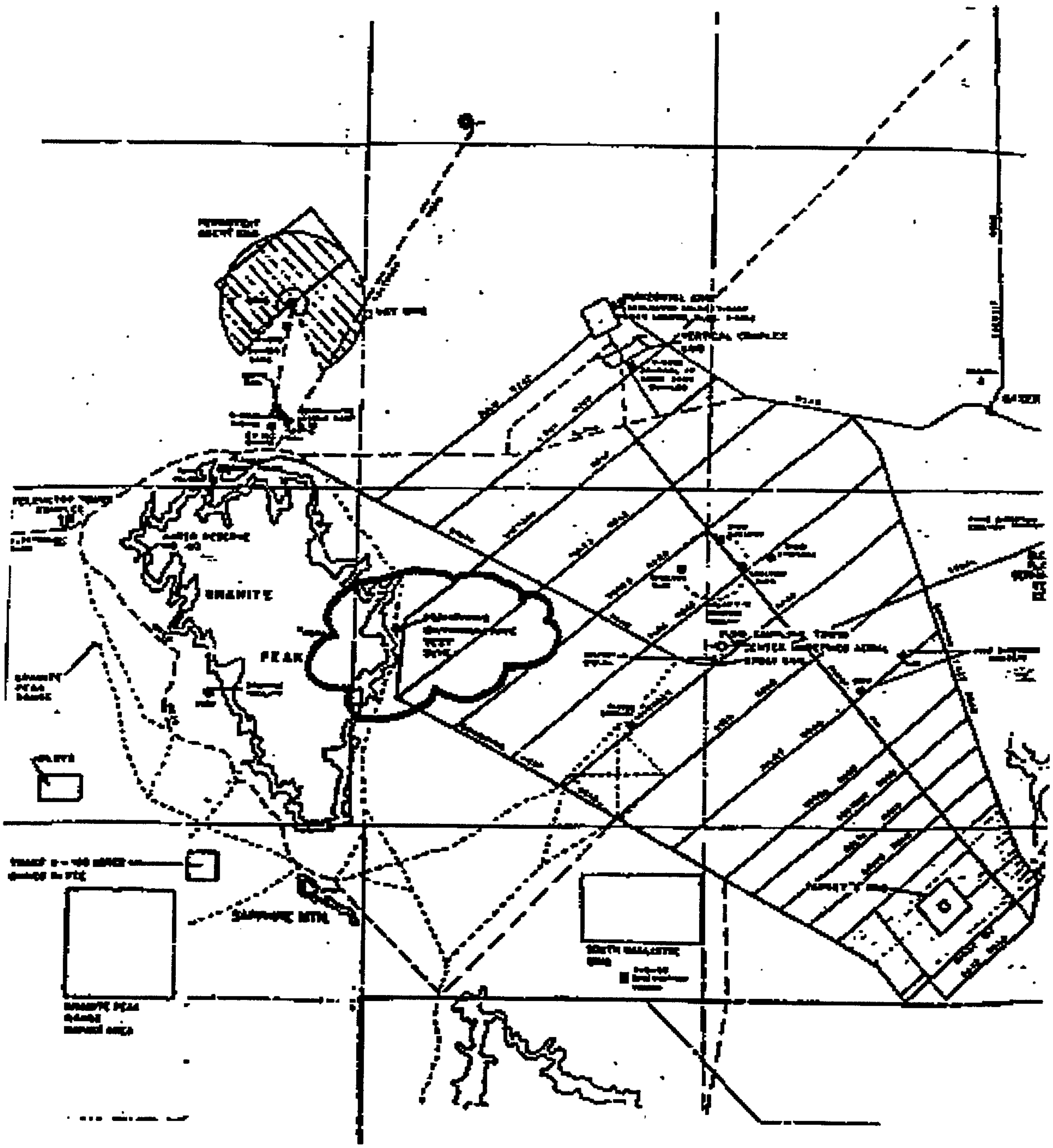


Figure 2
Dugway Proving Ground Map

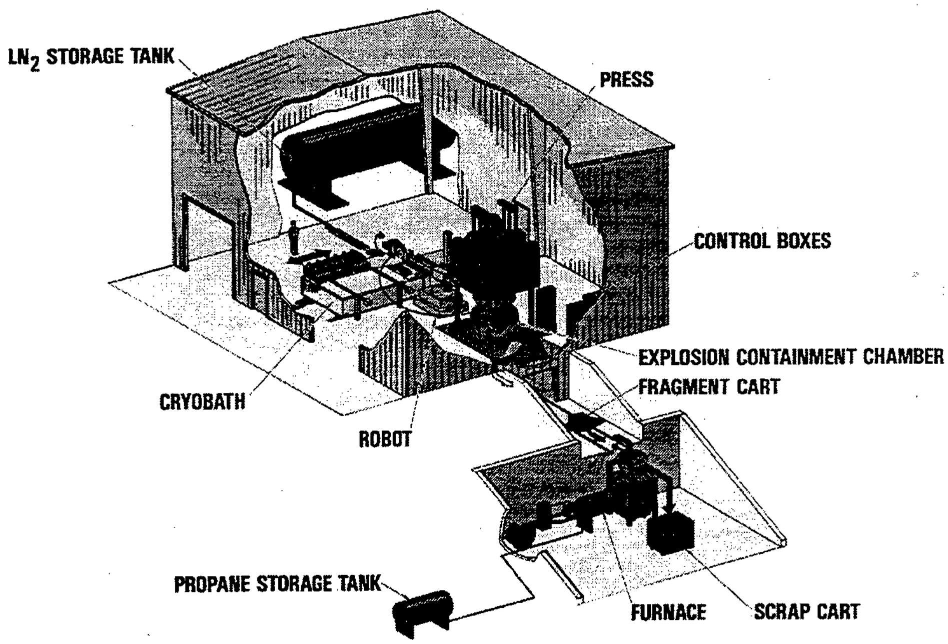


Figure 3
Munitions cryofracture test facility layout

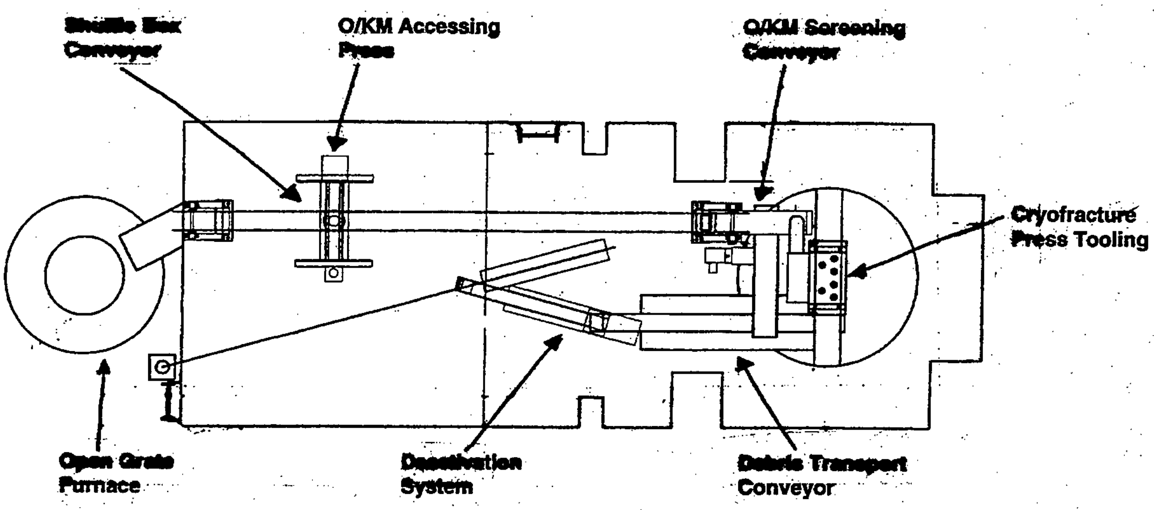


Figure 4
Equipment arrangement plan

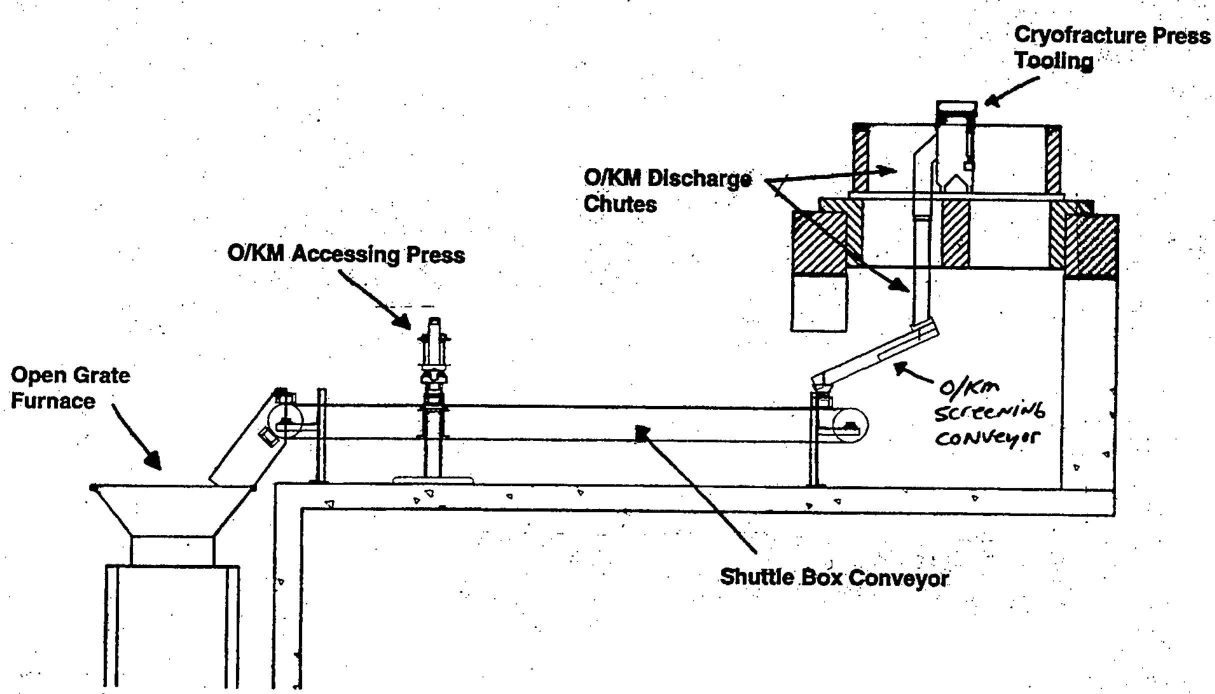


Figure 5
Equipment arrangement elevation

The cryobath is rail mounted to permit movement relative to the munitions handling robot. The cryobath translation mechanism consists of a motor driven sprocket and a fixed chain. The motor and speed reducer produce an approximately constant translation speed of 4 ft/min. The 750:1 speed reducer also acts as a brake to prevent movement when the cryobath is not being driven. Limit switches are used to automatically position the cryobath for robotic loading and unloading of munitions. A munitions loading platform allows placement of the munitions for pickup by the robot. Figure 6 shows loaded munitions in a transport fixture in position on the cryobath loading platform. The cryobath has a capacity of up to 1,400 gal. Of LN_2. LN_2 is stored in a 6,000 gal. Tank located outside the building.

Munitions are remotely handled by a Prab Model FC robot using reusable munition transport fixtures (fig. 7). The robot removes the fixture from the cryobath loading platform, places it in the cryobath, removes it from the cryobath after suitable cool down time, accurately places it on the press tooling, discharges the munitions on the tooling, removes the transport fixture from the press tooling, and sets it back onto the cryobath loading platform. The robot uses an end effector designed to pick up the munition transport fixture. The Prab robot uses a programmable motion controller to control and sequence all motions and input/output functions.

The use of reusable transport fixtures allows for economical operations by reducing the number of fixtures required during operations. The fixtures allow for accurate munition placement and downstream process equipment that does not have to account for cryofractured fixtures. Each munition type uses a different transport fixture.

The press is a modified Erie 750 ton, four post model with a 48-in. stroke and a 105-in. daylight. The press tooling is mounted on a beam that spans a central cavity in the press base. The press is mounted on a concrete foundation. A transfer cart is mounted under the base cavity for gravity discharge of munition fragments. In order to provide separate discharge paths for the O/KMs and the mine housing debris during ADAM mine testing, the transfer cart was removed and a series of discharge chutes were added. It was decided to keep the discharge chutes in place during processing of the M16 series mines and the Rockeye bomblets.

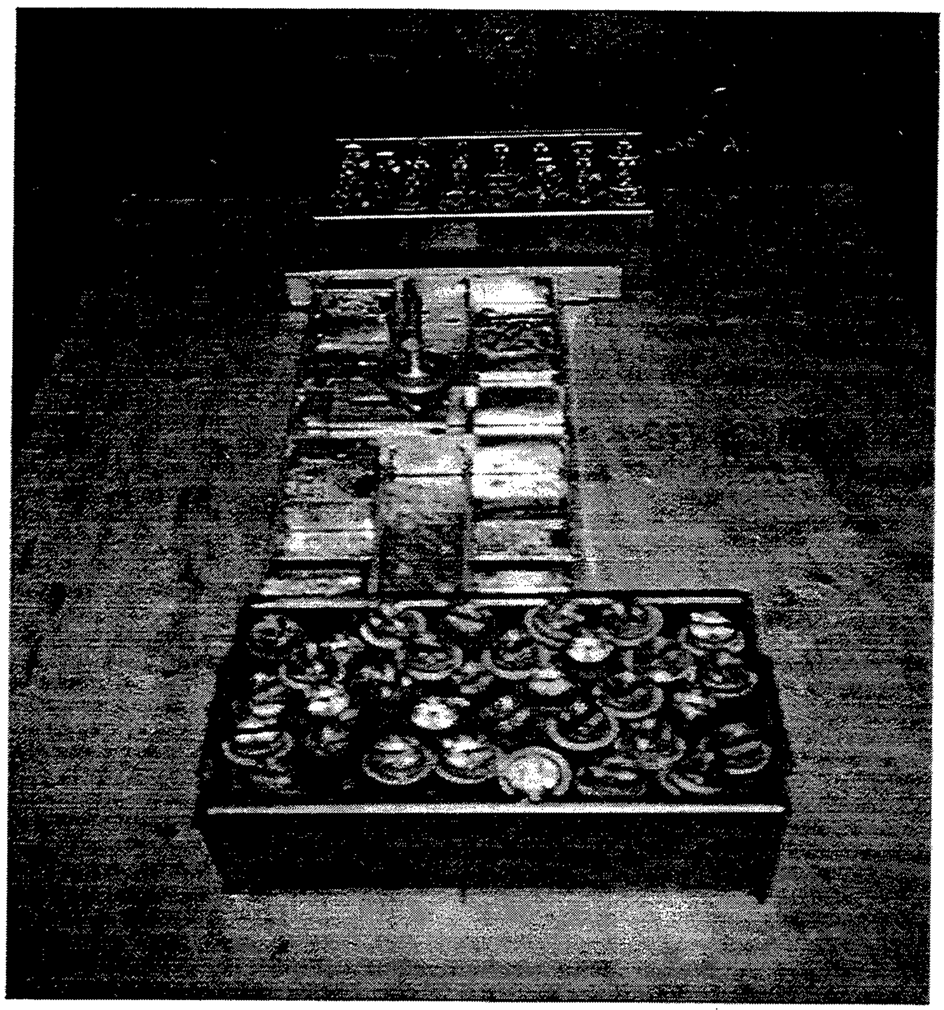


Figure 6
Munitions on cryobath platform

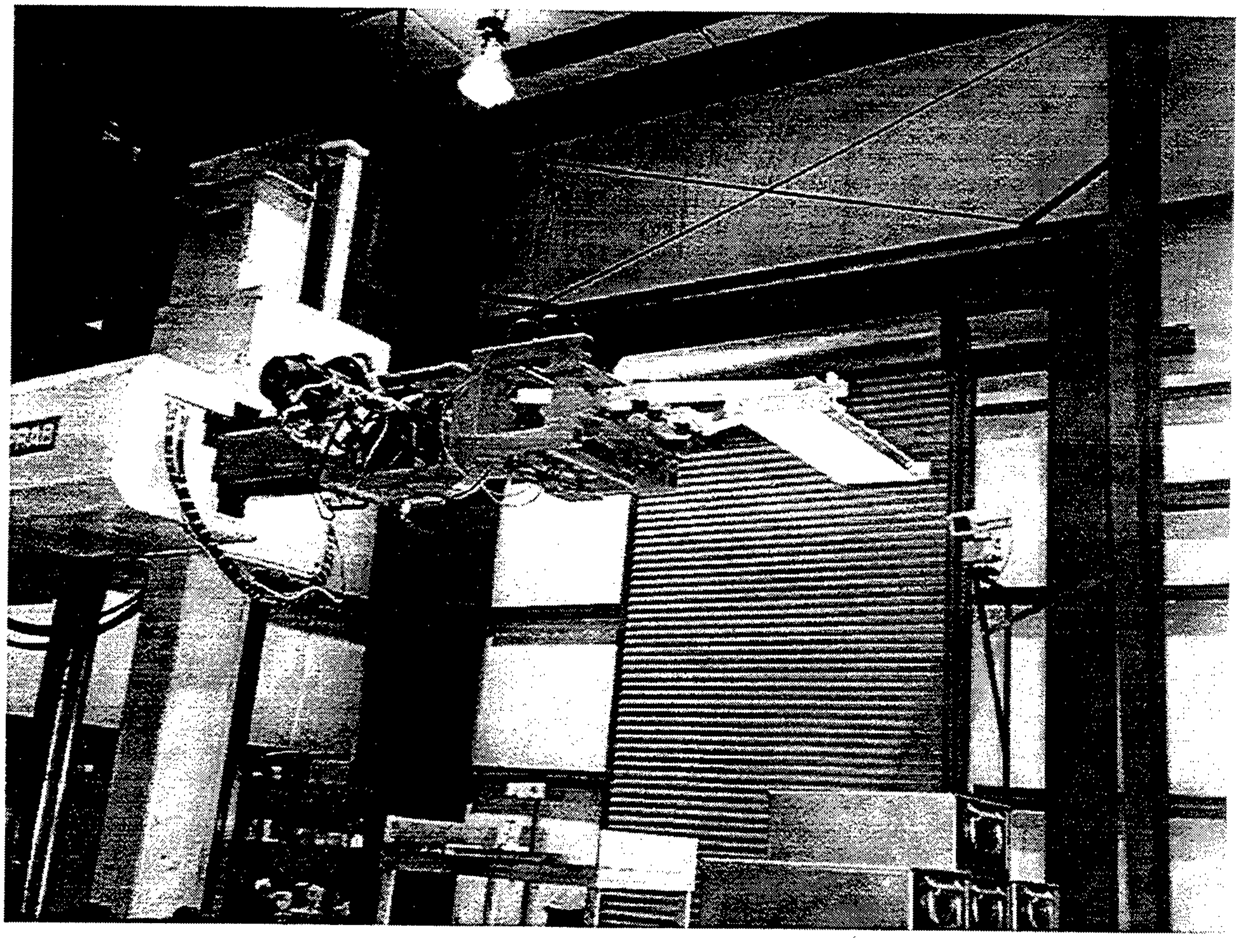


Figure 7
Prab robot handling munition transport fixture

The press incorporates an explosive containment chamber assembly consisting of 6-in. thick steel rings. The purpose of this assembly is to protect the press and other equipment from fragments and to protect the press hydraulics in the unexpected event of an explosion during fracture operations. When a munition is fractured, the two 6-in. thick steel rings enclose the munition and press tooling.

Following fracture in the press, the non-ADAM mine cryofractured munition debris drops into a custom designed chain-driven shuttle box conveyor (fig. 8). The remotely actuated shuttle box transports the debris to the open grate furnace (fig. 9).

For ADAM mine testing, the press tooling fractures the mine housing and separates the O/KM from the housing debris. The O/KMs and any residual debris are gravity discharged from the press tooling and fed to a vibratory screening conveyor. This conveyor removes residual material from the O/KMs (either directly attached or accompanied with the O/KMs) and the O/KMs are gravity fed to a shuttle box (fig. 10). The goal of the cryofracture and debris screening processes is to insure that, prior to incineration, the O/KMs contain the least possible amount of mine housing epoxy material.

The shuttle box is attached to a chain conveyor that transports the O/KMs to a small (50-ton) shop press where they are accessed. The shuttle box is then transported to a location in front of the open grate furnace where it is inverted to dump the O/KMs into the furnace grate. The shuttle box conveyor then returns the empty shuttle box to the O/KM discharge chute for reuse.

The non-O/KM cryofractured debris is separately discharged by gravity from the press tooling [via the tilt table that tilts at 50 deg when activated (fig. 11)] and conveyed to a debris deactivation system. The debris generated from the O/KM screening conveyor is also fed into the debris deactivation system. The deactivation system is comprised of the debris deactivation transport conveyor and the induction heating system. Two types of transport conveyors were tested: a vibratory tube conveyor and a screw conveyor. Both conveyors transported the debris through an induction heating system. The screw conveyor was judged superior to the vibratory type conveyor during ADAM QA testing and was used exclusively for ADAM AP testing.

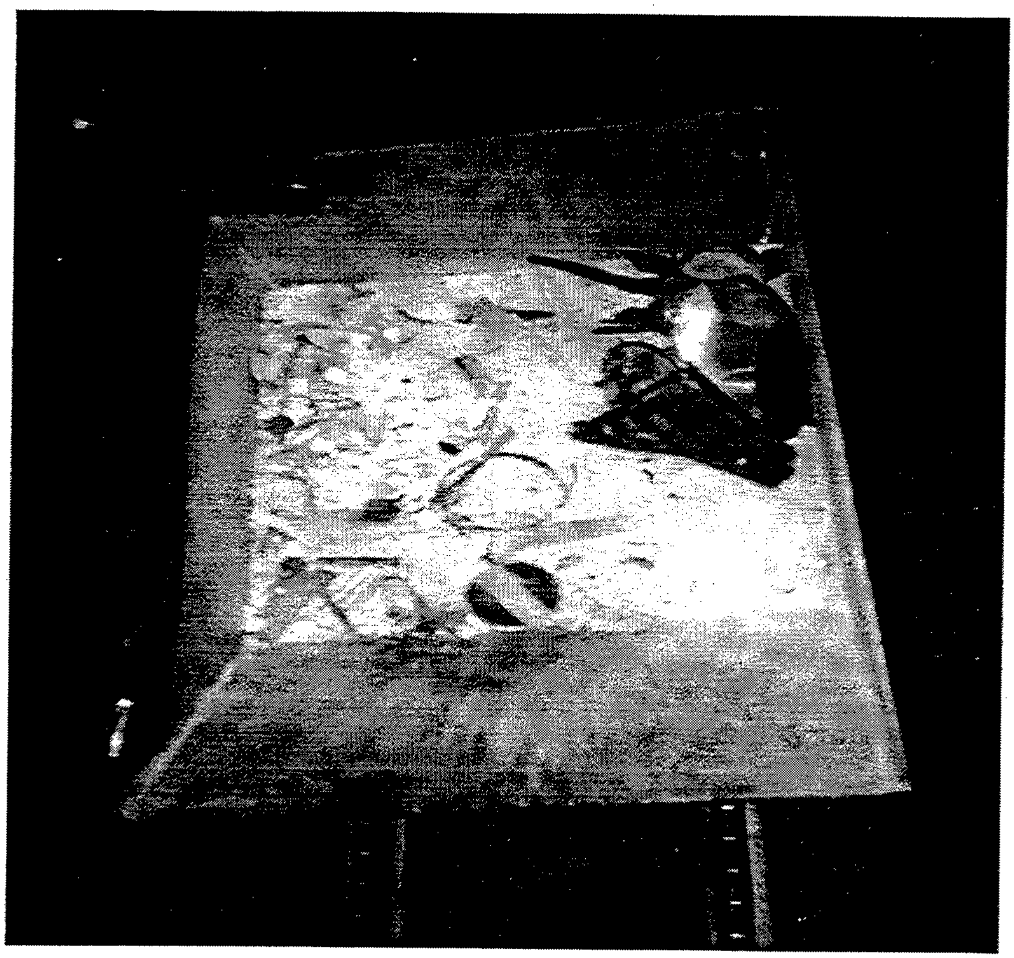


Figure 8
Non-ADAM mine shuttle box

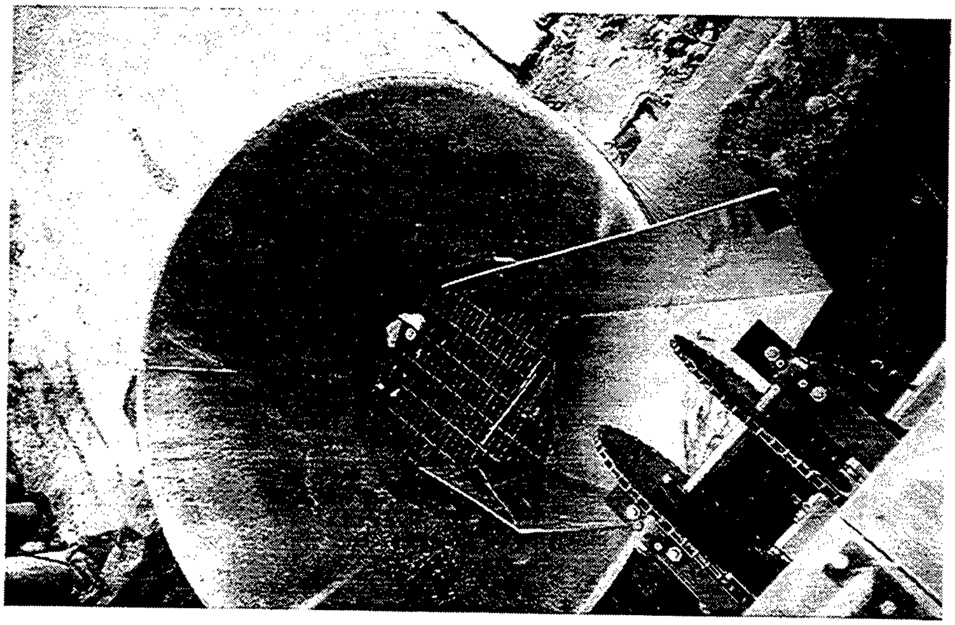


Figure 9
Shuttle box dump to open grate furnace

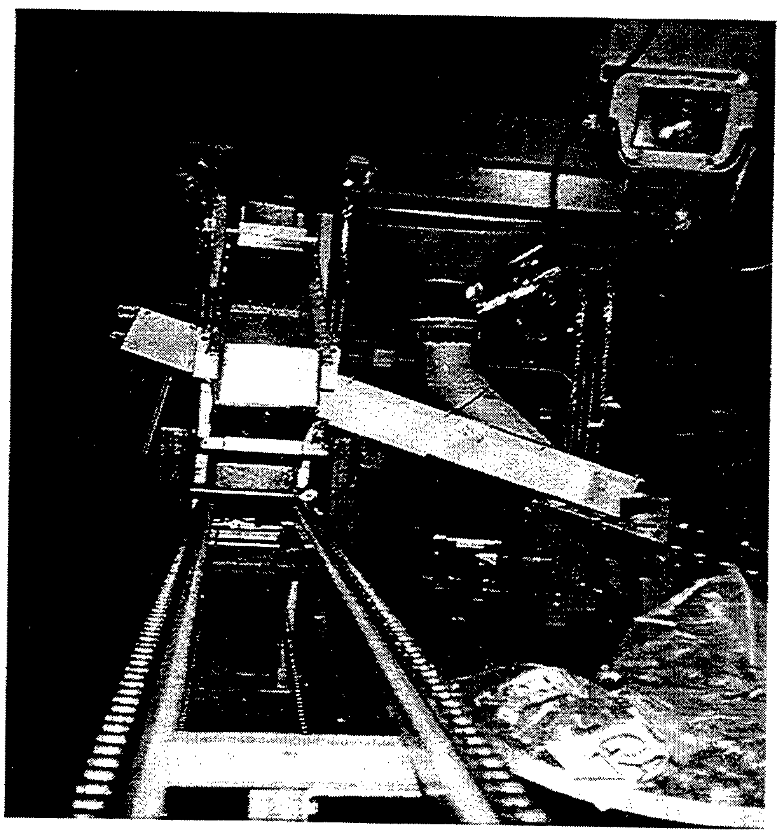


Figure 10
O/KM discharge chutes and shuttle box

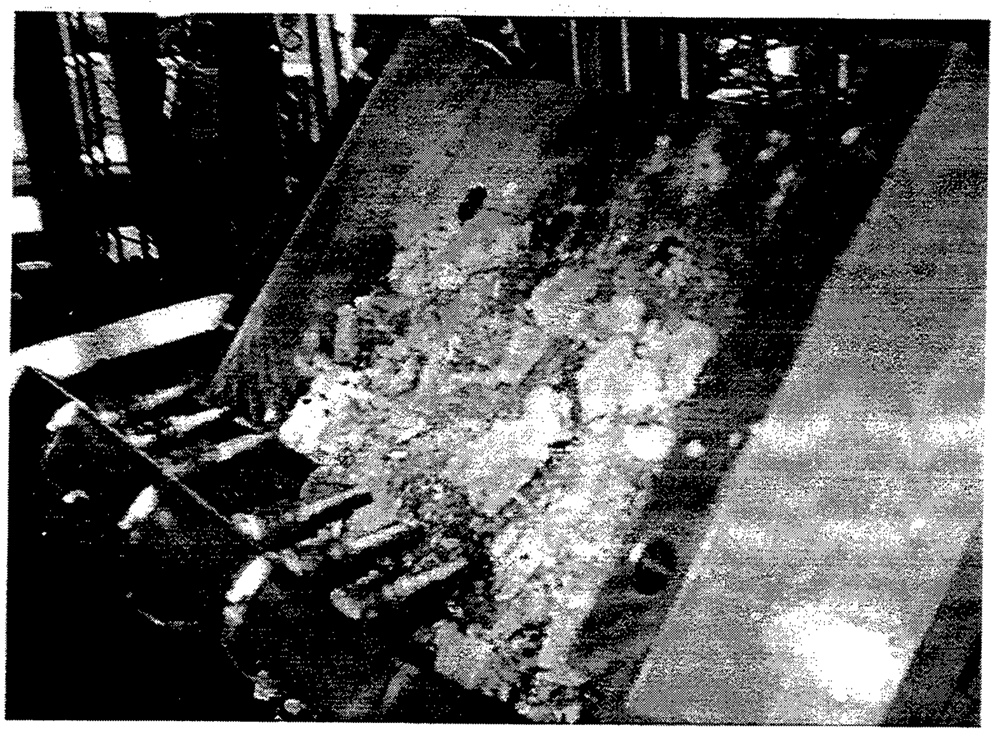


Figure 11
Tilt table discharge

Induction heating deactivation involves subjecting the safe and arming (S&A) assembly and gas generator (GG) assembly to an intense electric field comprised of low frequency photons (in the frequency range of 24,000 Hz) operating at very high current (450 amps) and voltage (630 V). This field heats the metal surrounding the S&A and GG and, by conduction, heats the energetic material within these components. The energetic material functions (detonates) when it reaches approximately 350°C. In addition, the field heats the metallic portions of the transport conveyors to ensure that any loose energetics associated with the debris are also deactivated. The residence time in the electric field was varied during testing to establish the optimum rate.

The custom designed open grate furnace is a two million BTU/hr, propane fueled, forced air unit (fig. 12). A centrifugal blower supplies combustion and excess air. The open grate contains a movable basket that permits the remote extraction of metal fragments after burning. The furnace grate is made up of three layers of grating material that can easily be replaced if damage occurs. Two 1,000 gal. Tanks and a vaporizer supply propane to the furnace.

Deactivated debris from the ADAM mine deactivation system was collected in drums, analyzed, and shipped to a metals recycling firm to determine if it is feasible and economical to retrieve precious metals (fig. 13). Scrap metal from the open grate furnace including the ash was drummed and removed from the site for landfill burial.

The press, robot, and cryobath are housed in a 50 ft x 50 ft metal building (fig. 14). The building is heated and air conditioned. The debris conveyors, induction heater, shuttle box conveyor, and the debris collection system are housed in a smaller building off to the side of the main building (fig. 15). Eight CCTV cameras are installed at key positions in the facility to provide test personnel with visual confirmation that the critical steps in the test operations are performed successfully. Electric power for the building was provided by a variety of 200 kW diesel generators.

Operational control and data acquisition is performed by a supervisory computer located in a 40-ft trailer. The control center trailer is located behind an earthen berm approximately 600 ft from the test facility building. The supervisory computer, a Data General MV/2000, supports a multiprocessing/multitasking environment for real-time process control. The computer is interfaced to the

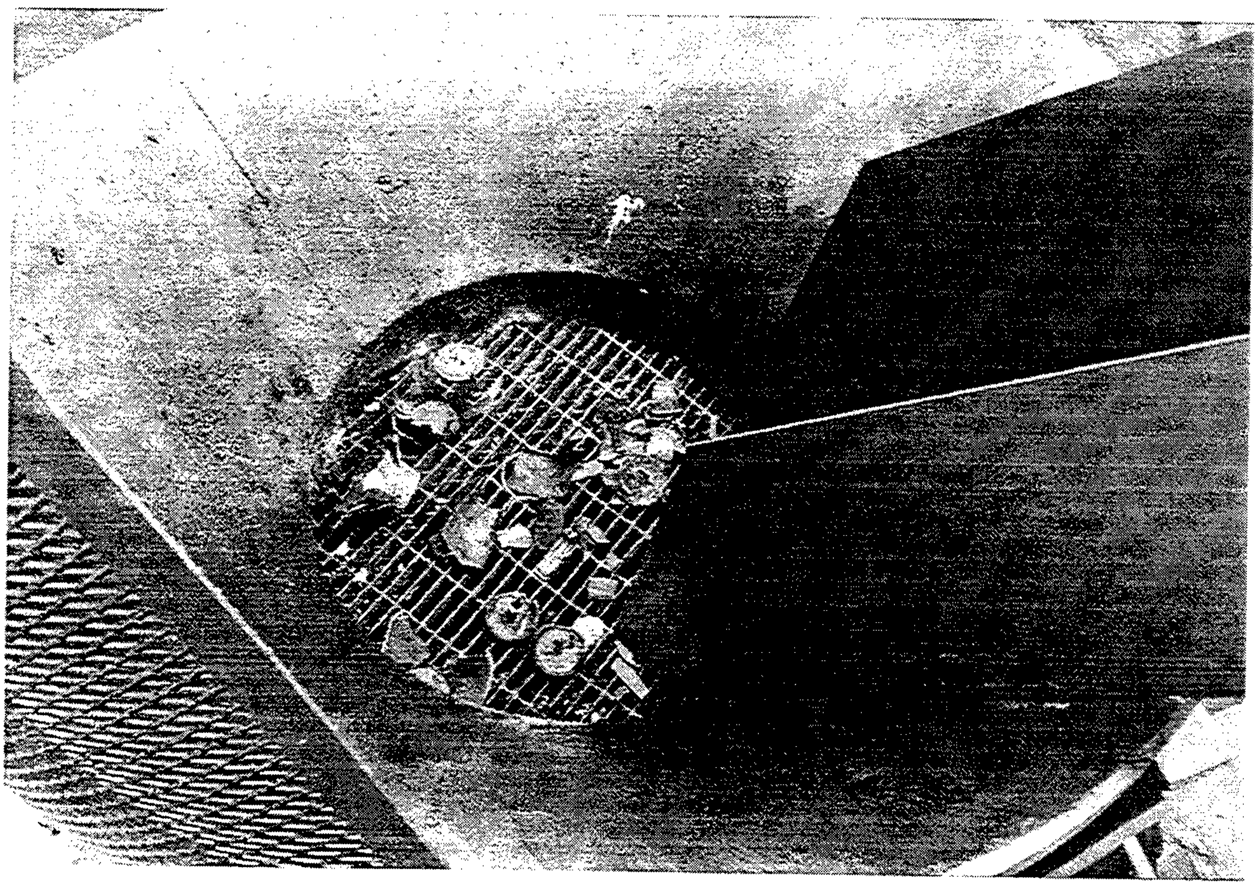


Figure 12
Open grate furnace

Figure 13
Drums with deactivated debris for shipment to metals recycler

Figure 14
Munitions cryofracture test facility

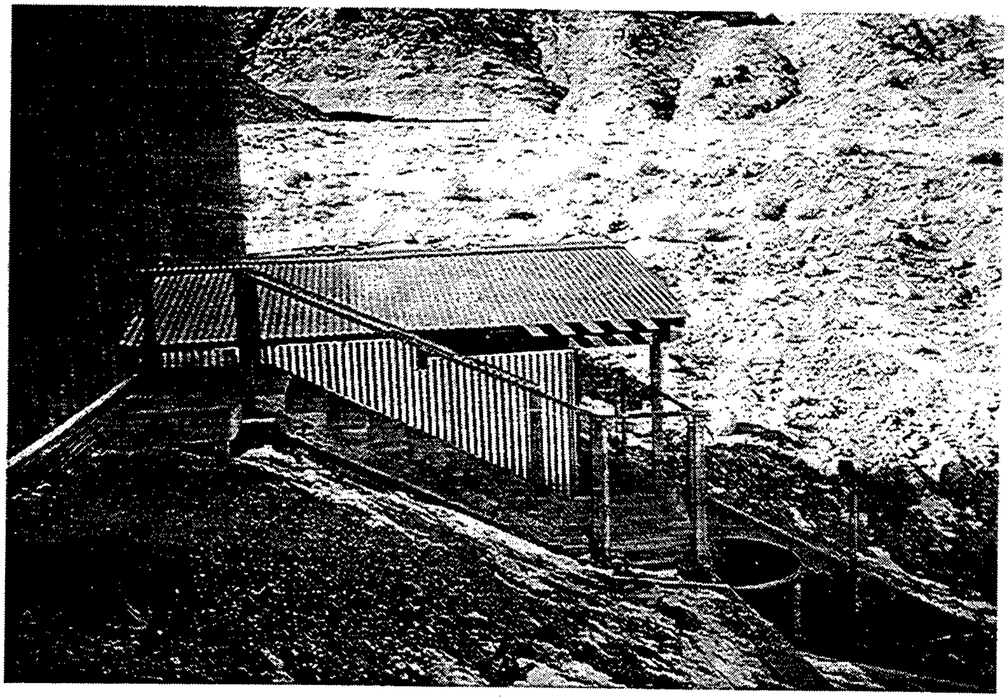


Figure 15
Cryofracture test site - tunnel area

facility via shielded cables. A nine track tape drive is used for data archival. The control center trailer also houses CCTV monitors, VCRs, control terminals, graphic display terminals, and supporting printers (fig.16). Electrical power for the control center is provided by various 80 kW diesel generators.

The supervisory computer controls and monitors the process (cryobath, robot, press, shuttle box, vibratory conveyors, deactivation system, and open grate furnace), collects the required data, and monitors a variety of alarms. All process events are recorded on a printer with time and date stamps that log all operations. The graphic displays provide operators real-time displays of process values and graphs of process trends.

A mobile munitions storage magazine, parked approximately 1200 ft from the test facility building, was used for temporary storage of explosively configured munitions.

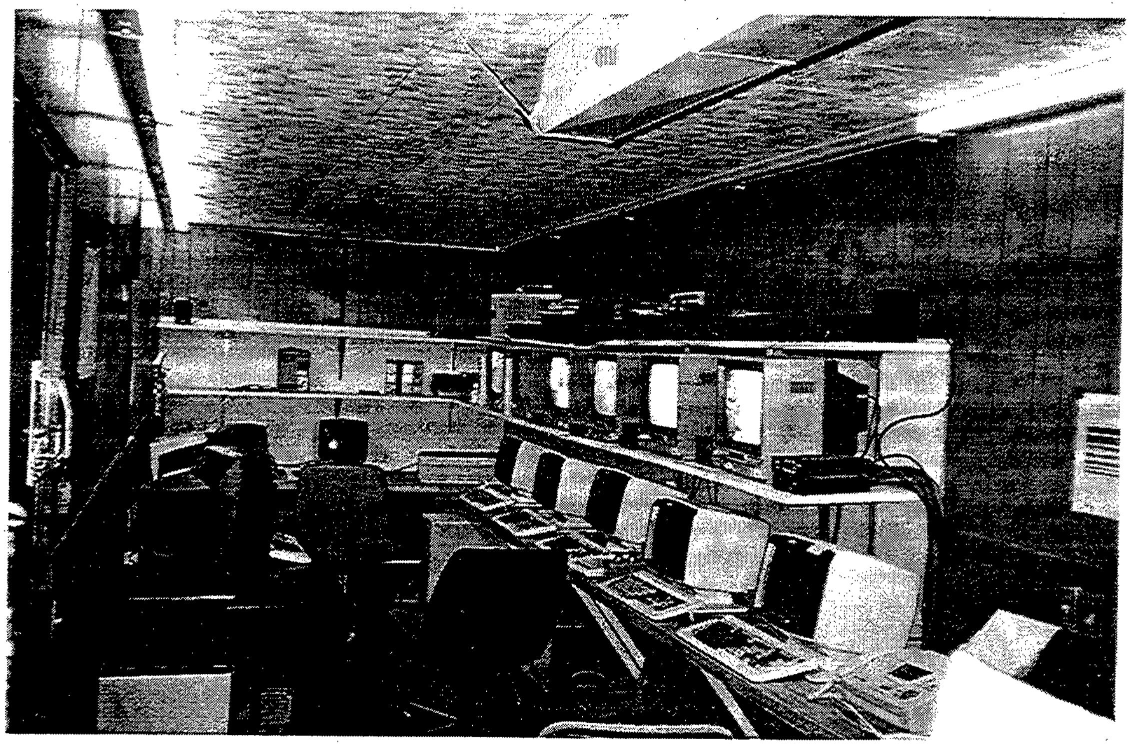


Figure 16
Control room

TEST ARTICLE DESCRIPTION

The test articles included four types of inert munitions, four types of live (explosively configured) munitions, three types of munition transport fixtures, one type of specialized robot grippers for the munitions transport fixtures, two specialized press tool sets for fracturing the munitions, one specialized press tool set for accessing the O/KMs, two specialized shuttle box containers for ADAM mine O/KM accessing, two deactivation system conveyors, and an induction heating system. In addition, a hydraulic press, press explosive containment chamber (ECC) components, a cryobath, and a munitions handling robot provided operations that are functionally prototypic of a production demilitarization facility.

Munitions

The type and quantity of munitions cryofractured are summarized in table 2.

Table 2
Munitions cryofractured

Munition type	Inert munitions	Live munitions
M483A1 projectiles containing 24 inert M46 and 64 inert M42 grenades	11 (616 grenades)	None
ADAM QA mines	42*	100
ADAM AP mines	0	360
Rockeye II MK 118 bomblets	21	247
M16 AP mine	4	61

*These were previously functioned ADAM QA mines from YPG.

Table 3 lists the characteristics of the M483A1 projectile, Rockeye II MK 118 bomblet, and the M16 AP mine. The inert M42/M46 grenades contained safety clips, but did not contain safety pins or nylon ribbon stabilizers. Table 4 lists the characteristics of the ADAM mine. All munitions were supplied by the Government and delivered to WDTC by the Government.

Table 3
Munitions characteristics

Munition type	M483 – 155-mm projectile	M16A2 AP mine	Rockeye II MK 118 bomblet
Length	80.3 cm w/o plug	11.9 cm w/o fuze	34.5 cm
Diameter	15.5 cm	10.3 cm	5.3 cm
Weight	Total w/o fuze 41.3-47.0 kg 24 M46 grenades @ 209 gm ea. 64 M42 grenades @ 200 gm ea.	2.72 kg w/o fuze	599 gm
Main explosive	2.68 kg Comp A5 – 30.5 gm in each grenade	590 gm TNT	180 gm Comp B
Fuze type	M223 – packaged separately (not cryofractured)	M605 – packaged separately (not cryofractured)	MK 1, Mod 0, w/M55 detonator, lead cup assy w/135 mg Tetryl
Delay detonator	NA	140 mg Black powder 150 mg Lead styphanate 350 mg Lead azide	NA
Booster	NA	11.18 gm Comp A5	4.6 gm RDX, composition CH-6
Expulsion charge	58.0 gm M10 propellant	4.53 gm black powder	NA

Table 4
ADAM mine characteristics

Geometry	6.589 cm long, 72° sector of a 12.814 cm diameter cylinder (thick pie wedge)
Construction	Components imbedded in an epoxy material containing 0.096 gm of a depleted Uranium salt in the form of Uranyl Acetylacetonate (UAA)
Weight	417 gm
Main Explosive	20.851 gm Comp A5
Housing, Timing and Fuzing	196gm epoxy (including UAA)
Kill Mechanism and Overlay Assembly (O/KM)	
Detonating Cord Assembly	
Detonation Cord	0.070 gm RDX, Type II, Class 7
Booster Cup	0.022 gm PBXN-5
Overlay Assembly	0.290 gm EGDN Liquid propellant
Kill Mechanism Assembly	
Upper Shell Assembly	10.600 gm Comp A5
Lower Shell Assembly	10.251 gm Comp A5
Delay Detonator	0.025 gm RDX, 0.038 gm Lead Azide, 0.041 gm Delay Comp 9298732
Propellant Nut	0.013 gm Propellant 9298437
Safe & Arm Assembly (S&A)	
M100 Electric Detonator	
Spot Charge	0.0008 gm Lead Styphnate
Charge Cup	0.016 gm HMX, 0.014 gm Lead Azide
Lead Cup Assembly	0.019 gm PBXN-5
Gas Generator Assembly (GG)	
Output Charge Assembly	0.015 gm Lead Styphnate, 0.052 gm Black Powder

Munition Transport Fixtures

Three types of munition transport fixtures (corresponding to each of the three munition types) were tested to transport the munitions into the cryobath, transport the munitions from the cryobath to the press tooling, and accurately deposit the munitions on the press tooling. The fixtures were constructed primarily of aluminum with a handle on top for robot attachment. The ADAM mine transport fixture was designed to carry up to six ADAM mines (fig. 17). The Rockeye II MK 118 bomblet transport fixture was designed to carry up to seven bomblets (fig. 18). The M16 AP mine transport fixture was designed to carry up to three mines.

The ADAM mine and M16 mine transport fixtures used a slideable bottom tray that held the munitions in place unless pulled out on side tabs. During fixture insertion into the press tooling, tabs on the bottom tray engaged metal posts on the tool set. This forced the bottom tray to slide out and release the munitions. The tray was raised to clear the munitions and, as the fixture was retracted from the tool set, the metal posts hit the tabs and slid the bottom tray back into the transport fixture. The ADAM mine transport fixture used metallic sliders using ball bearings; the M16 mine transport fixture used ultra high molecular weight (UHMW) sliders for tray sliding. The UHMW sliders were judged to be superior due to reliability (fewer moving parts and no frosting or galling) and smooth operation.

The Rockeye II bomblets transport fixture used a slideable tail-fin tray. In this configuration, the bomblets were supported by their tail-fins and their nose assemblies. As the slideable tail-fin tray moved outward, the bomblets were deposited onto the tooling. While this method worked, it is not recommended for extended Rockeye II demilitarization due to the possibility of the bomblets falling out of the fixture.

Robot End-effectors

One type of robot end-effector was used to pick up the munition transport fixtures. The robot end-effector had a duel function: (1) to hook onto the transport fixture from the top for cryobath operations and (2) to attach to the transport fixture from the side for press tooling operations (fig. 19).

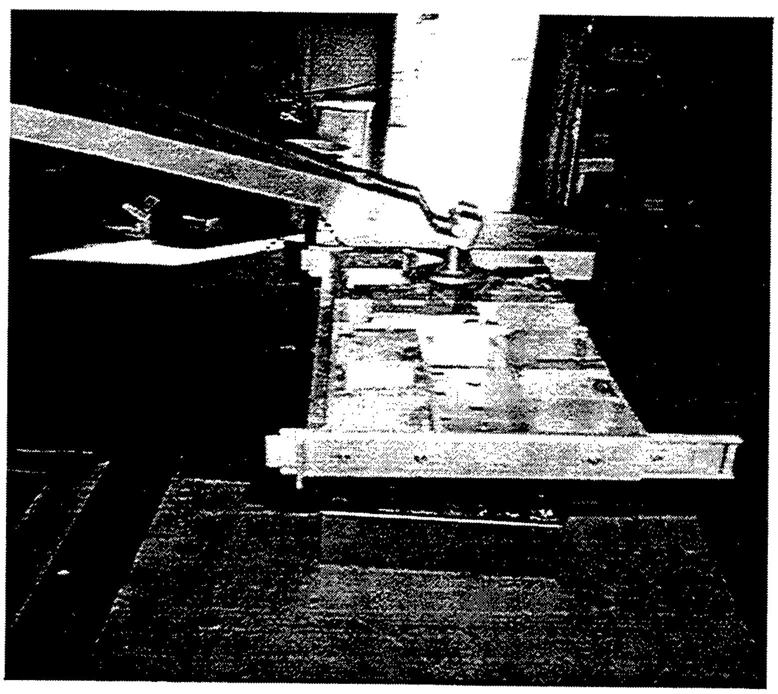


Figure 17
ADAM mine transport fixture

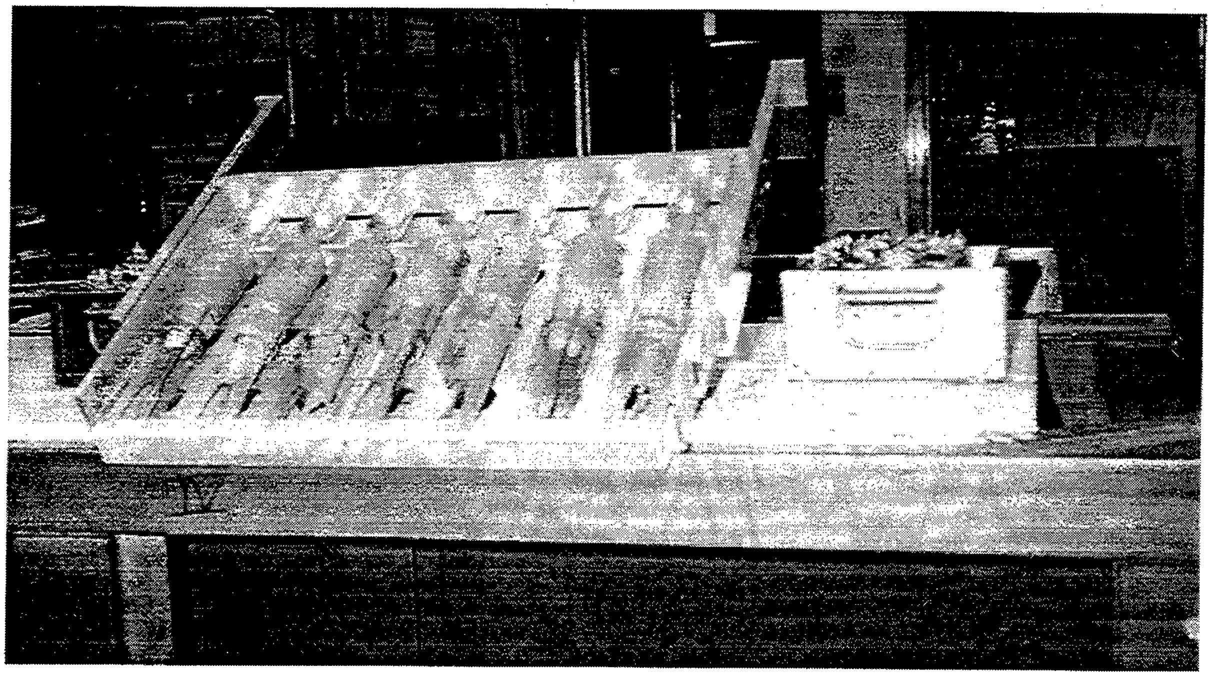


Figure 18
Rockeye II bomblet transport fixture

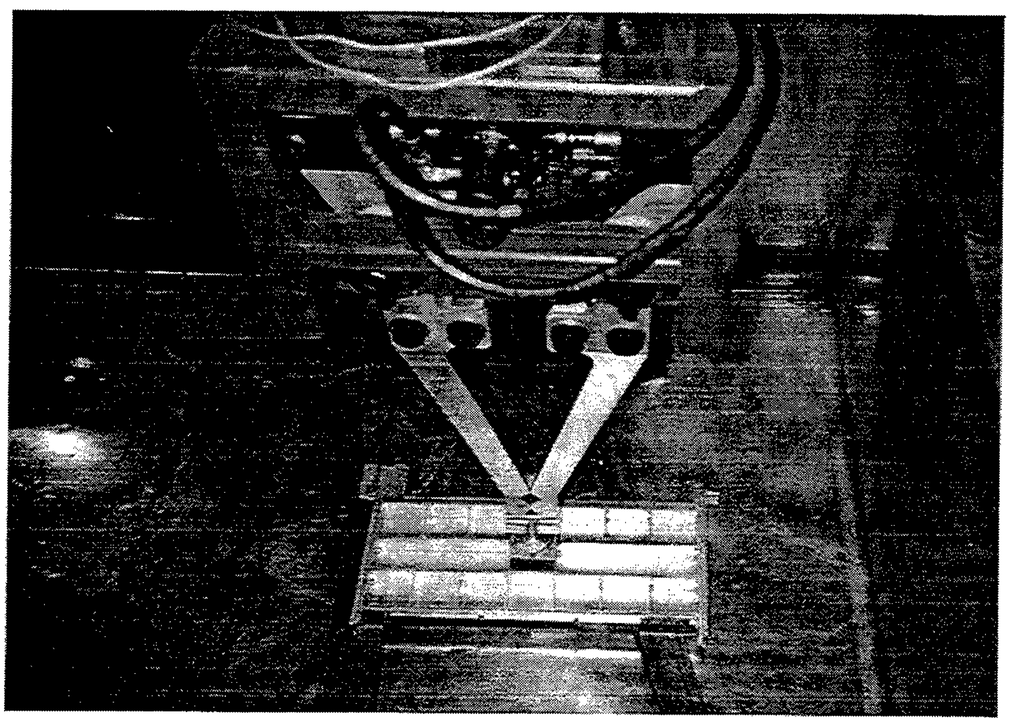


Figure 19
Prab robot transport fixture end-effector

Press Tooling

The inert M483A1 projectile tests used two different tool sets: a modified version of the M23 landmine tooling for flat plate crushing and a new tool set that provided a controlled crush of the munition. The tooling originally developed for cryofracturing M23 landmines is described in reference 1. The tooling for controlled crushing of a M483A1 projectile is described in reference 2. In order to minimize cost, the M483A1 tooling did not provide for discharge of debris; the tooling required manual clearing following each cryofracture.

The ADAM mine tests used a punch and die tool set designed to cryofracture six mines. This tool set is described in reference 3 and shown in figure 20. The upper tooling consisted of a flat plate with six protruding punches to remove the O/KMs from the mine housing. The lower tooling is a flat plate with holes to accept the punched-out O/KMs. The punched-out O/KMs fall through internal channels where they are discharged. The remainder of the ADAM mine housing is crushed by the upper and lower tooling flat plates. The cryofractured mine housing debris is discharged by a pneumatically operated tooling tilt table.

The M16 AP mine tests and the Rockeye II bomblet tests used modified versions of the ADAM mine tooling for flat plate crushing. The upper punches were removed and flat surface inserts where installed. A plate was installed in the lower tooling to cover the O/KM discharge holes. A scalloped plate was used for the Rockeye bomblets and a smooth surface plate was used for the M16 mines. The live M16 AP mine tests and the live Rockeye II bomblet tests also used the pneumatic tilt table feature to discharge debris following the cryofracture. The tooling for the M16 mines and Rockeye II bomblets is described in reference 4 and shown in figure 21.

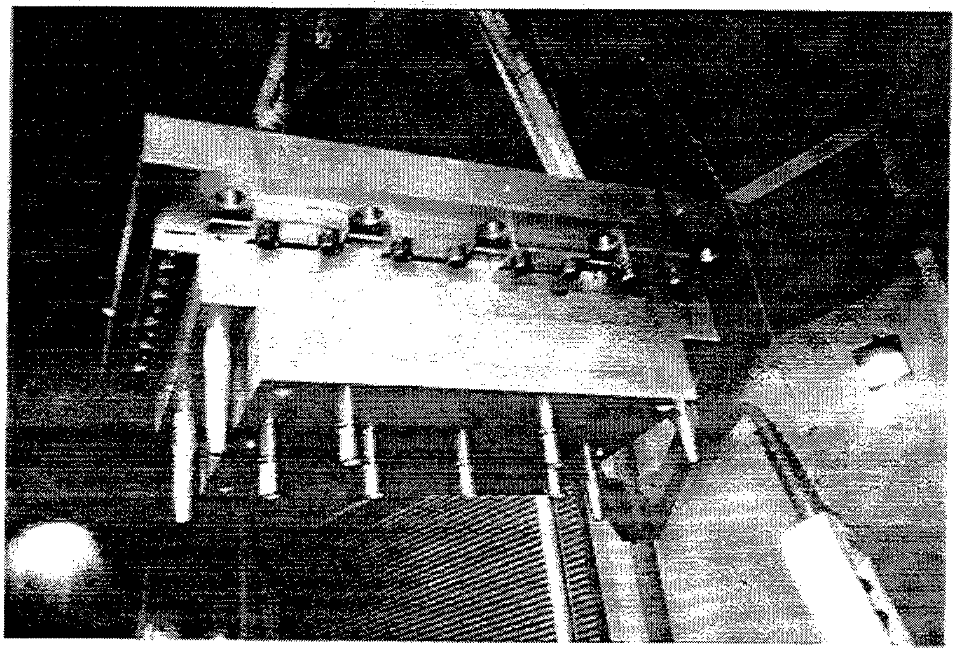
O/KM Accessing Tooling

The ADAM mine tests used a small shop press to access the O/KMs. The tool set for this shop press consisted of an upper flat plate punch. A shuttle box containing the O/KMs moved along a chain track and into the shop press. This punch pressed into the shuttle box to break open and access the O/KMs. After accessing, the shuttle box moved out of the press and the contents were dumped into the open grate furnace. This upper punch is described in reference 4 and is shown with the O/KM accessing press in figure 22.

Shuttle Boxes

The non-ADAM mine tests used an aluminum shuttle box with a pour spout. The only function of the shuttle box was to transfer the entire cryofractured debris including the energetics from the press discharge chute to the open grate furnace.

The ADAM mine tests used two types of shuttle boxes. These shuttle boxes were used to transport the O/KMs from the press discharge chute to the accessing press and then to the open grate furnace. The shuttle boxes also provided the lower crush surface for the O/KM accessing. The first shuttle box type used a flat plate bottom. This shuttle box combined with the upper punch from the small press performed flat plate crushing on the O/KMs. During one of the ADAM mine tests, a number of KM's detonated in the O/KM accessing press. The O/KM shuttle box was changed from a flat plate bottom to a scalloped bottom. The scalloped bottom allowed accessing of the KM while minimizing crushing of the central detonator column. The scalloped shuttle box is shown in figure 23.



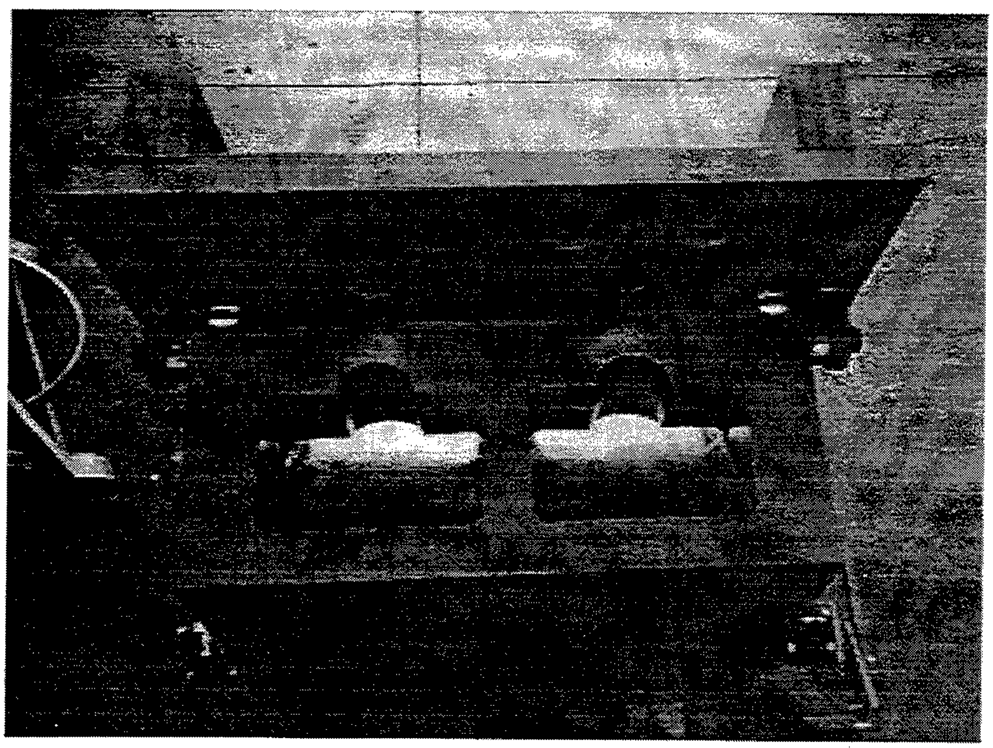


Figure 20
ADAM mine upper and lower press tooling

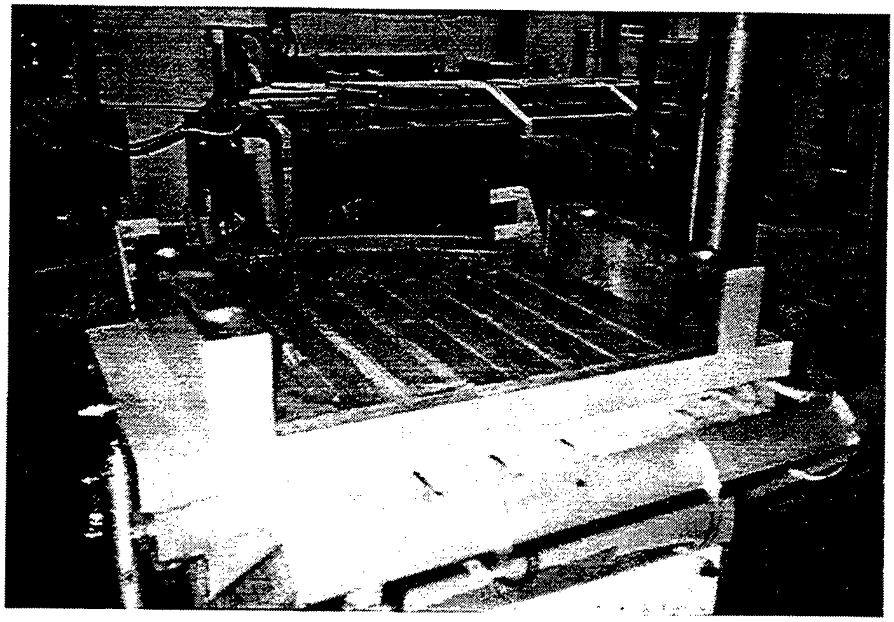


Figure 21
Rockeye II press tooling

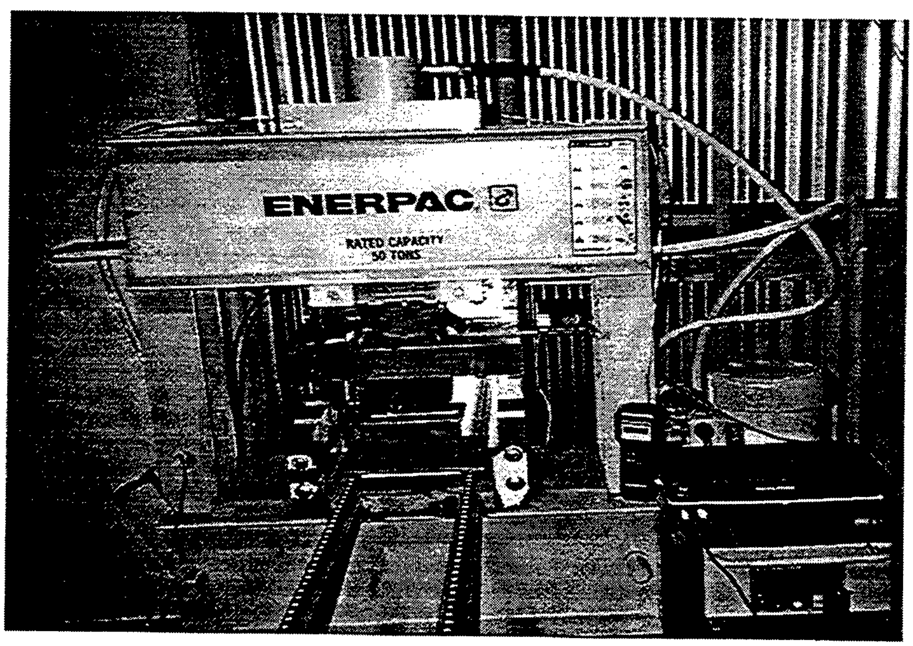


Figure 22
ADAM mine O/KM upper punch and accessing press

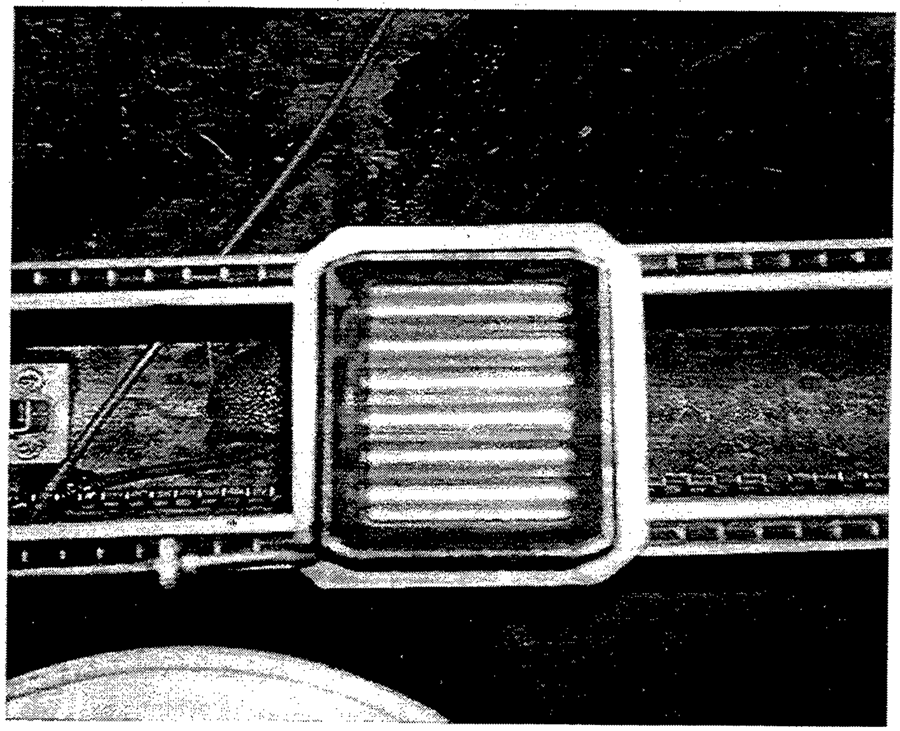


Figure 23
ADAM mine O/KM shuttle box

Deactivation System Conveyors

The ADAM mine tests used two types of deactivation conveyors. One system is a simple vibratory tube conveyor (fig. 24) using magnetics to vibrate a tube as a function of the 60 HzV sine wave. A full wave electrical supply powers the conveyor to operate at full speed; a partial wave (clipped or phased) decreases the speed of the conveyor. The second conveyor is a screw conveyor controlled by a variable frequency drive controller. The speed by which these conveyors pass the energetic material through the induction coil field (residence time) affects deactivation. The screw conveyor was judged to be superior to the vibratory tube conveyor because the material flow rate was more reliable (which establishes reliable residence time) and the effect of the induction coil on the metallic conveyor parts and the metallic energetic parts was much improved. The screw conveyor without the non-conductive thermal cover is shown in figure 25.

Induction Heating System

The deactivation system consisted of an induction coil wrapped around the deactivation conveyor powered by a field generator. A nitrogen purge system was used in the deactivation conveyor to minimize epoxy burning. The basic electrical diagram (fig. 26) identifies the field generator (F), the capacitors (C), and the induction coil (L and R). During system operations, the coil frequency is generated by the resonance frequency created by the coupling effect of the capacitance of the capacitors (C) and the inductance of the coil (L). The strength of the magnetic field is a function of the voltage (V) applied across the capacitors and the current (I) flowing through the induction coil. The combination of these parameters directly affects the susceptor temperatures (conveyor liner wall, screw conveyor flights, and the metal-encased energetic debris inside). ADAM mine debris contains not only S&A and GG components, but may also contain Comp A5 powder (from prematurely cryofractured KMs) and liquid propellant (from ruptured overlays). The induction coil coupled with the geometry of the conveyor must ensure even heating for complete deactivation of all energetics present in the debris. Figure 27 shows the effect of the induction heating coil on the conveyor liner wall and the screw conveyor flights.

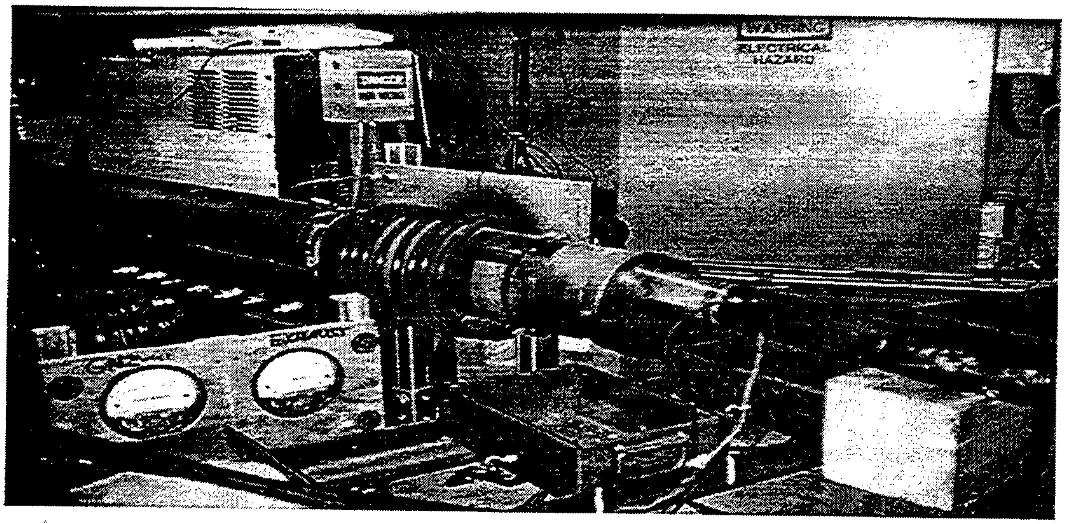


Figure 24
Deactivation vibratory tube conveyor

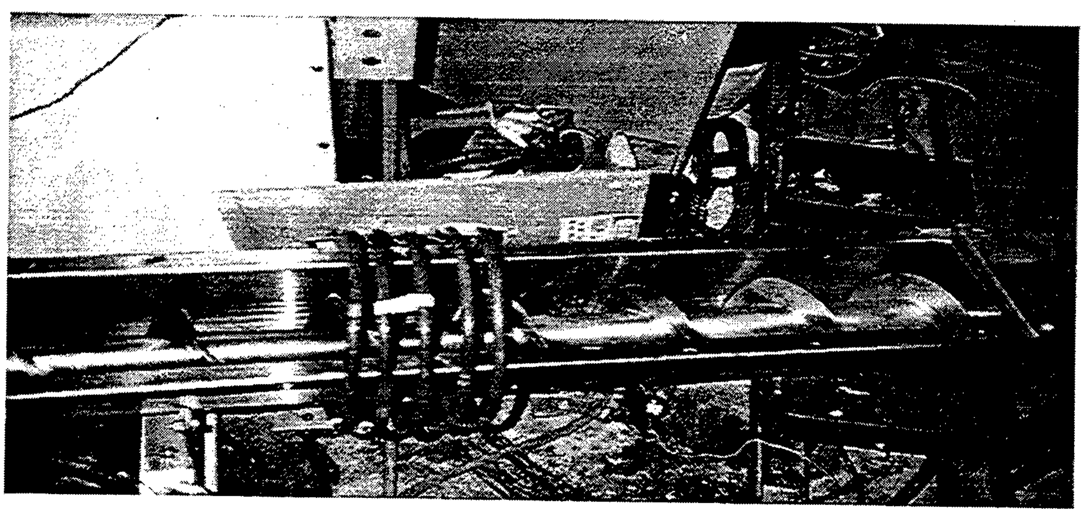


Figure 25
Deactivation screw conveyor without cover

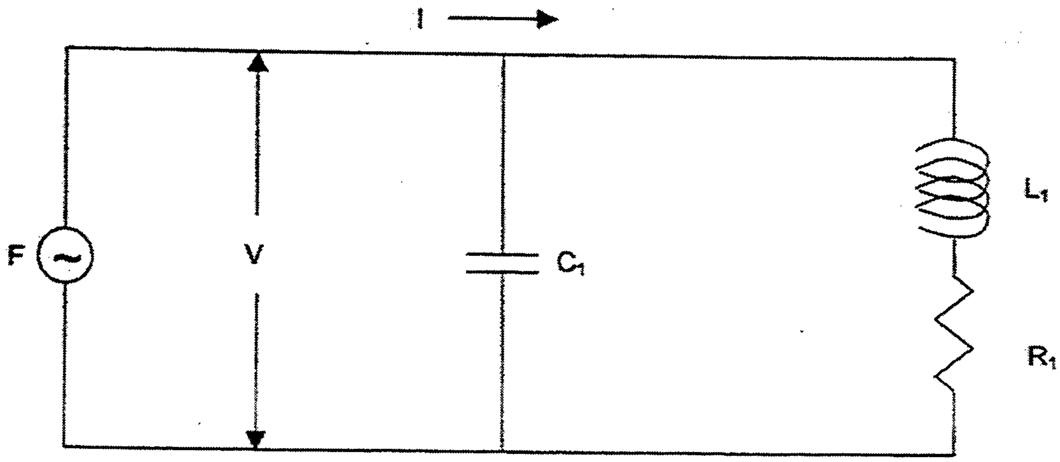
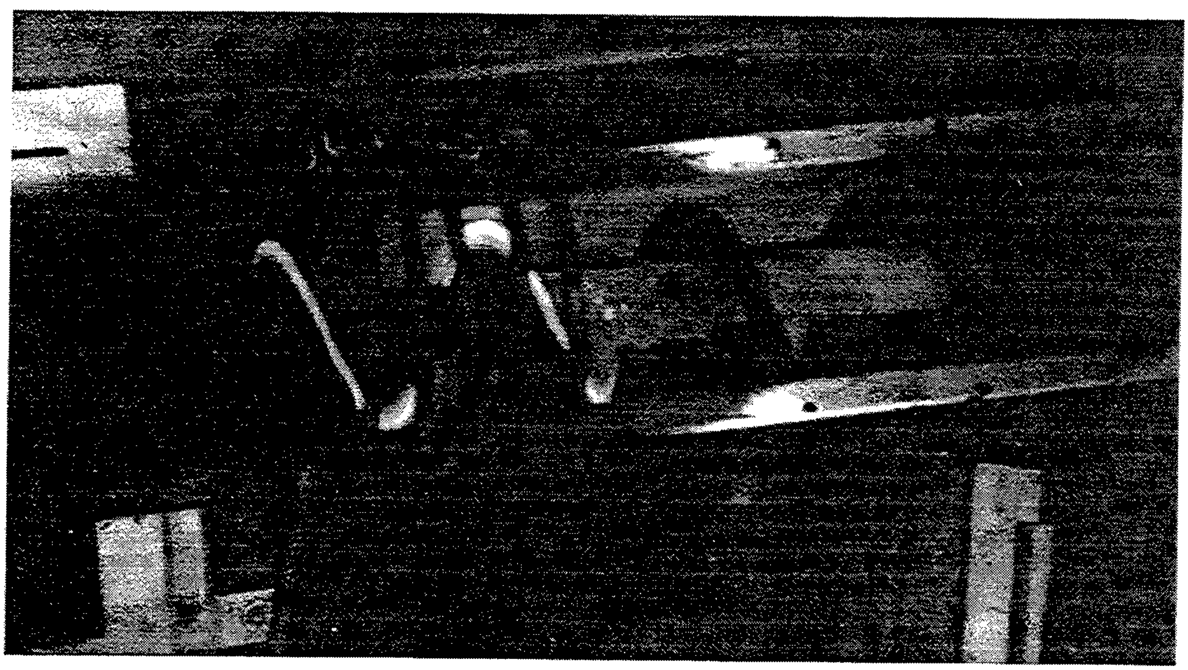


Figure 26
Induction heater equivalent circuit



(Picture was taken in the dark to show glowing metallic parts)

Figure 27
Induction heating coil effects on screw conveyor

The deactivation system used gaseous nitrogen to minimize the burning of epoxy as the material passed through the heated section of the conveyor. An emission collection system drew exhaust gases from the deactivation system and passed these gases through a filter to the atmosphere. The filter was later sampled for particulates. The gaseous nitrogen and the emission collection system used separate magnehelic gauges (fig. 28) to measure pressures during system operation. The effect on the deactivation process was to establish a face velocity through the deactivation system that gently purged the system with nitrogen while removing off-gas emissions without causing a cooling effect and without drawing oxygen into the deactivation system.

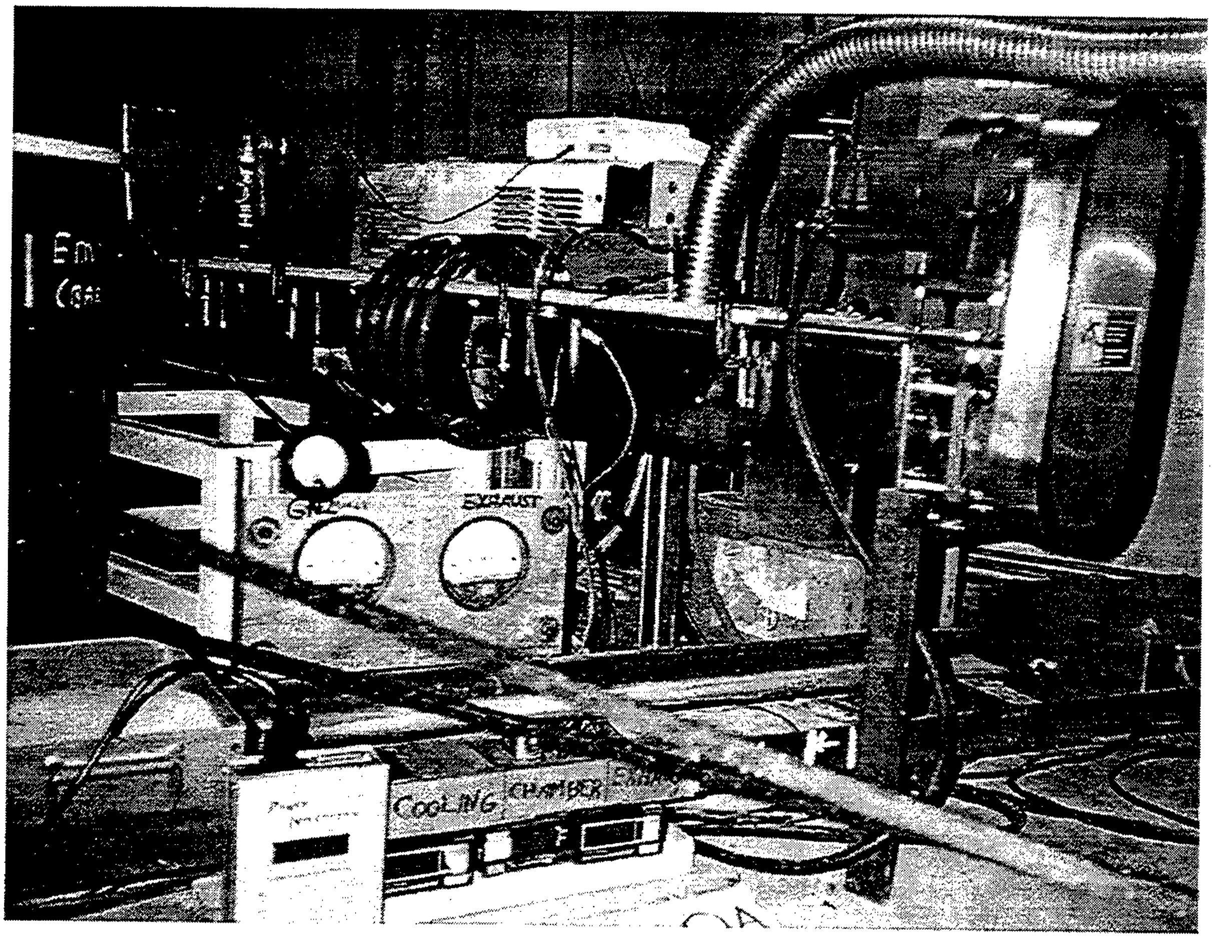


Figure 28
Deactivation system with GN2 purge and emission collection system

TEST RESULTS

ADAM QA and AP Mines

TEAD Adam Mine Tests

A series of ADAM mine demilitarization tests was conducted to evaluate potential techniques for cryofracture accessing and debris processing. These precursor tests were conducted in late June 1998 at the Tooele Army Depot (TEAD) in order to develop design data required for the WDTC testing. Both QA and AP versions of the ADAM mine were used for the tests. Fifteen QA mines were cryofractured to obtain preliminary data on ADAM mine orientation, cool down time, press tooling parameters, crush heights, and S&A and GG deactivation methods. The data obtained from these tests were then used as initial conditions for a series of 37 cryofractures of AP mines. The last 30 AP mine tests used the same press tooling configuration (punch and die diameters) and the same debris crush height (0.75 in.). A summary report of the testing performed at TEAD is in the appendix.

Inert ADAM QA Mines

Following design, setup, and installation of equipment at the DPG MCTF, a series of 11 cryofractures of 36 inert mines was performed to finalize the parameters and checkout the equipment to be used in subsequent live ADAM mine cryofractures. True inert ADAM mines do not exist; therefore, ADAM QA mines that were previously functioned at YPG were shipped to DPG for use. These mines allowed "hands-on" functional checkout of MCTF components (e.g., robot and transport fixture operations, press punch and cryofracture operations, deactivation transport conveyor operations, etc.) to be verified and tuned prior to live ADAM mine testing. Table 5 summarizes the tests performed with these inert mines.

Tests 1 through 6 were performed in local manual mode with single ADAM mines in order to monitor the ADAM mine throughout the cryofracture process. During these tests, portions of the process required fine tuning. This included adjusting the robot programming and transport fixture points for pickup and placement in the press tooling, modification of discharge chutes, and deactivation system tuning (vibratory tube conveyor, induction heating, gaseous nitrogen supply, and emission collection). Test 7 was run in local mode with six ADAM mines to verify that the process could handle the six mines. Tests 8 through 10 were run in remote mode from the control room using the integrated process control system with six ADAM mines to finalize system operations, software, alarms, procedures, setpoints, and safety interlocks prior to live testing. Test 11 was performed for a DPG mandated Operational Readiness Inspection (ORI). This test was run in local mode so that the ORI staff could view the process.

During the majority of these tests (QA tests 1 through 11), it was a surprise to encounter simulated aluminum overlays and simulated metallic kill mechanisms (iron balls). Normally, ADAM QA mines have small lead shot with epoxy mix as the simulated kill mechanism core (all other components are "live"). Although a surprise, these QA mines were used to additionally checkout the O/KM handling portion of the process.

Table 5
Test results summary - "inert" ADAM QA mines

Test date	Test no.	Number of mines	Cool down time (min)	Press Closure Spacing (in,)	Fracture load (tons)	Comments
1/20/99	1	1	10	1.5	62	All mechanical components operated well (robot, cryobath, press, conveyors, shuttle box) during this test. Simulant O/KM was punched out and discharged as expected. ADAM mine housing was fractured and discharged. System run in manual-local control mode. These QA mines had simulated kill mechanisms (iron balls) and aluminum overlays rather than the normal lead shot.
1/21/99	2	1	10	1.5	62	Entire cryofracture system worked well. Excellent mine cryofracture and O/KM punch-out. Simulant O/KM was hung up in discharge chute. Discharge chute was modified to prevent O/KM hang-up. System run in manual-local control mode.
1/25/99	3	1	10	1.5	61	Cryofracture system worked well including deactivation transport and induction heater. Excellent mine cryofracture and O/KM punch-out. GN2 flows balanced with emission collection system online. System run in manual-local control mode.
1/25/99	4	1	10	1.5	62	Entire cryofracture system worked well. Excellent mine cryofracture and O/KM punch-out. System run in manual-local control mode.
1/26/99	5	1	10	1.5	63	Entire cryofracture system worked well. Excellent mine cryofracture and O/KM punch-out. ARDEC personnel in attendance during test. System run in manual-local control mode.
1/26/99	6	1	10	1.5	62	Entire cryofracture system worked well. Excellent mine cryofracture and O/KM punch-out. ARDEC personnel in attendance during test. System run in manual-local control mode.
1/26/99	7	6	10	1.5	82	Entire cryofracture system worked well. Excellent mine cryofracture and O/KM punch-out. ARDEC personnel in attendance during test. System run in manual-local control mode.
1/27/99	8	6	10	1.5	79	Entire cryofracture system worked well. Excellent mine cryofracture and O/KM punch-out. ARDEC personnel in attendance during test. System run in remote automatic mode.

Table 5
(continued)

Test date	Test no.	Number of mines	Cool down time (min)	Press closure spacing (in.)	Fracture load (tons)	Comments
1/27/99	9	6	10	1.5	80	Entire cryofracture system worked well. Excellent mine cryofracture and O/KM punch-out. System run in remote automatic mode.
1/28/99	10	6	10	1.5	75	Entire cryofracture system worked well. Excellent mine cryofracture and O/KM punch-out. System run in remote automatic mode..
2/1/99	11	6	10	1.5	76	Test performed to demonstrate system to WDTC personnel for WDTC ORI. Entire cryofracture system worked well. Excellent mine cryofracture and O/KM punch-out. System run in manual-local control mode for WDTC personnel close-up observation.

Live ADAM QA Mines

A series of 21 cryofractures of 100 live ADAM QA mines was then successfully performed to demonstrate the feasibility of the debris separation/deactivation system. Table 6 summarizes these tests. The ADAM QA mines were automatically and remotely processed through the cryobath using the transport fixtures and, after 10 minutes, accurately placed on the press tooling. The press punched out the simulated O/KMs and crushed the mine debris. The simulated O/KM was discharged to the shuttle box conveyor where it was transferred to the O/KM accessing press, crushed, and then dropped into the open grate furnace. The open grate furnace was not operated; a metal catch container was used to capture the simulated O/KMs. The cryofractured mine debris containing the S&A and GG was discharged to conveyors and transported through an induction heating system to deactivate the energetics. Tests 1 through 12 used a vibratory tube conveyor for deactivation transport and tests 13 through 21 used a screw conveyor. The screw conveyor was judged to be superior to the vibratory tube conveyor as it provided a more positive means of debris transport through the induction coil.

Most of the 21 ADAM QA tests were performed to establish a reliable and repeatable residence time by which S&A and GG items could be deactivated. This involved a complex balance of parameters of residence time and deactivation temperature. The residence time was directly affected by the transport conveyor speed. The deactivation temperature was a function of the coil frequency, current, voltage, coil geometry, and the air flow through the system produced by the gaseous nitrogen purge and the gas emission collection system. Deactivation was verified by visual examination of the debris.

ADAM mine QA tests 1 through 3 determined that the vibration amplitude (set to small amplitude) required for the vibratory tube conveyor was not strong enough for proper residence time. The effect was that the material being transported in the vibratory tube conveyor jammed at spots and, once built up, would stay jammed. The system was switched to a high-amplitude setting which, in effect, would vibrate the conveyor in such a manner to prevent jamming. However, the

Table 6
Test results summary -- ADAM QA Mines

Test no.	Test date	No. of mines	Cool down time (min)	Tooling air flush reqd?	Coil power level (kw)	Debris residence time* (min:sec)	All energetics deactivated (S&A,GG)?	Comments
A1	2/1/99	3	30:15	No	4.0	35	No	Initial problems with remote operation of equipment. System repair and mechanical process worked well, but deactivation system did not deactivate energetics.
A2	2/2	1	12:00	No	5.0	58	Yes	Increased deactivation coil power level and reduced deactivation conveyor speed prior to test.
A3	2/2	3	10:10	No	5.0	30	No	Increased deactivation conveyor speed prior to test. Resulting speed was greater than expected.
A4	2/3	1	10:00	No	5.0	N/A	No	Deactivation conveyor switched to pulsed operation prior to test. Deactivation conveyor stopped before debris reached deactivation coil.
A5	2/3	1	10:05	No	5.0	55	Yes	Increased deactivation conveyor speed prior to test.
A6	2/3	6	10:05	No	5.0	35	No	Adjusted deactivation conveyor speed prior to test
A7	2/4	6	10:05	No	5.0	40	No	Adjusted deactivation conveyor speed prior to test.
A8	2/4	6	10:00	No	5.0	50	No	Reduced deactivation conveyor speed prior to test.
A9	2/8	6	10:00	No	5.0	58	Yes	Good deactivation.
A10	2/8	6	10:10	No	5.0	55	No	Reduced deactivation conveyor speed prior to test.
A11	2/8	6	10:03	No	5.0	55	Yes	Good deactivation.
A12	2/8	6	8:30	No	5.0	62	Yes	Operator prematurely commanded robot to remove mines from cryobath.
A13	2/11	1	10:10	No	9.2	75	Yes	Switched to screw-type deactivation conveyor prior to test.
A14	2/11	6	10:08	No	9.2	N/A	No	Deactivation conveyor screw jammed before debris reached deactivation coil.
A15	2/16	6	10:10	No	9.2	58	Yes	Deactivation conveyor switched to pulsed operation prior to test (on for 0.2 sec every 15 sec.)
A16	2/16	6	17:00	No	9.2	62	Yes	Operator requested incorrect robot program for removing the loaded transport fixture from the cryobath; robot was e-stopped and manually reset.
A17	2/17	6	10:05	No	8.0	64	No	Reduced deactivation coil power level prior to test.
A18	2/17	6	10:02	No	9.5	52	Yes	Increased deactivation coil power level prior to test. Good deactivation.

* Debris residence time measured the time in the coil. The coil was 10 in. long.

Table 6
(continued)

Test no.	Test date	No. of mines	Cool down time (min)	Tooling air flush reqd?	Coil power level (kw)	Debris residence time* (min:sec)	All energetics deacttivated (S&A,GG)?	Comments
A19	2/17	6	10:00	No	9.5	56	Yes	Press failed to cycle. Press cycle completed manually with good deactivation.
A20	2/17	6	10:10	No	9.5	51	Yes	Good deactivation
A21	2/17	6	10:00	No	9.5	58	Yes	Good deactivation

* Debris residence time measured the time in the coil. The coil was 10 in. long.

NOTE:

(1) Tests QA1 through QA12 used a vibratory type deactivation conveyor. Tests QA13 through QA21 used a screw type deactivation conveyor.

(2) All tests used the standard (flat, countersunk face) press tooling punch configuration with a crush height of 0.75 in.

high-amplitude setting had the undesirable effect of passing the material through the transport conveyor very quickly; hence, not an effective residence time. The solution was to add control circuitry to cycle the conveyor in a pulsed mode. A cycle was defined as the combination of the time that the conveyor was on (T_{on}) (for material transport motion) plus the time that the conveyor was off (T_{off}) (for residence time). After adjustment of the T_{on} and T_{off} by using many batches of previously deactivated ADAM mine epoxy debris manually dropped in the conveyor in local mode, the combined effects of high-amplitude (to prevent jamming) and the pulse mode (residence time) was determined suitable to maintain a repeatable residence time.

QA tests 4 through 8 used the vibratory conveyor in a high-amplitude, pulse mode setting. The vibratory conveyor amplitude was erratic -- sometimes the amplitude was low and sometimes it was very high. This caused unreliable residence time through the induction coil which yielded non-deactivated S&A and GG. The magnetic vibrator and reaction springs were cleaned and adjusted. QA tests 9 through QA 12 were run with all material deactivated except for a couple of items (1 GG and 2 S&As) in QA test 10.

After QA test 12, the vibratory conveyor was removed and replaced with a screw conveyor. A larger induction coil was installed and the conveyor speed adjusted for proper residence time. This was accomplished by reducing the motor supply line frequency to 4 Hz. The induction heater (larger coil affecting coupling impedance) was retuned, and the gaseous nitrogen and emission collection system was balanced. Many batches of six-at-a-time previously deactivated ADAM mine debris were processed through the system to verify operation.

QA test 13 processed one ADAM mine through the screw conveyor. This test successfully deactivated the mine debris. Six mines were used for QA test 14, which caused the screw conveyor to jam due to low screw speed (low frequency = low torque). The screw conveyor was modified to operate at maximum torque (60 Hz) with pulsing (T_{on} and T_{off}) to establish suitable residence time. Multiple batches (up to 18-at-a-time) of previously deactivated ADAM mine debris were processed through the system to checkout the system operation and to verify that pulsing at maximum torque solved the debris jamming problem.

QA tests 15 through 21 were performed to demonstrate that parameters selected for the cryofracture process (cool down time, press spacing, press fracture height, number of ADAM mine fractured per cycle, deactivation residence time, deactivation power level, gaseous nitrogen flow, and gas emission collection) were correct prior to testing ADAM AP mines. The power level of the induction field generator was decreased on QA test 17 to verify the critical power threshold. Not all of the energetics were deactivated for this test and the power level was returned to the previous level for subsequent tests. Except for QA test 17, all energetic materials during QA tests 15 through 21 were completely deactivated.

Live ADAM AP Mines

A total of 64 cryofractures of 360 live ADAM AP mines (up to six at a time) were successfully performed to demonstrate not only the cryofracture process but the additional process steps of the punch out of the O/KM and the subsequent accessing by a small press and incineration of the O/KM. These tests (summarized in table 7) used the same process parameters established from the ADAM QA tests.

All ADAM AP mine tests used the same transport fixtures, cool down time, press tooling, munition orientation and spacing, preset maximum press tonnage force, press crush height, deactivation power level, and deactivation residence time. All tests except AP test 11 used the same deactivation transport conveyor speed and pulse settings. For AP test 11, the conveyor pulse settings were changed to increase conveyor speed and decrease residence time. These settings were changed to verify the critical residence time threshold. One M100 detonator (part of the S&A) and two gas generators did not deactivate at the faster conveyor speed.

ADAM AP test 1 was performed with one mine and test 2 was performed with two mines to verify the cool down time and to verify that subsequent O/KM operations (discharge, screening, accessing, and incineration) functioned as planned. Starting with AP test 3, six ADAM AP mines were used for testing. Some minor problems, inconveniences, and required tune-ups were encountered during the AP testing. Most of these were facility related (diesel generators, hydraulic press, shuttle box chain drives, etc.) and were not related to prototypic items (e.g., transport fixtures, fracture press tool set) under test.

An attempt to measure the amount of epoxy associated with the O/KMs and the amount of epoxy burned in the deactivation system was made during AP tests 15 through 20. However, due to WDTC safety constraints, which prevented access to O/KMs (prior to and after accessing), actual weights of the epoxy associated with the O/KMs could not be determined. Instead, the debris was weighed prior to and after deactivation operations. Since the total weight of the mine is known along with the O/KM, an approximate weight of the debris remaining with the O/KM could be determined. A further approximation of the weight of the epoxy associated with the debris was estimated visually.

Table 7
Results summary for AP ADAM mines

Test no.	Test date	Air flush reqd?	Press fracture force (tons)	No. of O/KMs broken during fracture	Pop during O/KM assessing?	No. of large pops during furnace burn	Energetics deactivated (S&A,GG)?	Comments
AP1	2/17/99	Yes	72	None	No	None	Yes	Three tooling air flushes reqd. Normal fracture and furnace burn.
AP2	2/18	No	87	None	No	None	Yes	Normal fracture and furnace burn.
AP3	2/22	No	82	1	No	1	Yes	Normal fracture. Shuttle box conveyor failed. Warmed up O/KMs accessed and burned after shuttle boxy conveyor repairs. Normal furnace burn.
AP4	2/22	Yes	71	1	No	None	Yes	Normal fracture and furnace burn.
AP5	2/22	No	80	1	No	None	Yes	Normal fracture and furnace burn. Piece of epoxy debris stuck in tooling die hole after fracture. Dislodged during next fracture.
AP6	2/22	Yes	74	None	Yes	None	Yes	Normal fracture and furnace burn.
AP7	2/22	No	84	None	No	None	Yes	Normal fracture and furnace burn.
AP8	2/22	No	75	None	No	None	Yes	Normal fracture. An O/KM hung up in a tilt table discharge tube after fracture. Dislodged when table was titled up. Normal furnace burn.
AP9	2/22	Yes	73	1	Yes	None	Yes	Normal fracture. Multiple air flushed failed to remove debris stuck on a tooling die hole. This debris was removed by cycling the press. A broken O/KM hung up in a tilt table discharge tube and was dislodged when the tilt table was lowered. Normal furnace burn.
AP10	2/22	Yes	77	None	No	None	Yes	Normal fracture. Debris hung up in two die holes removed by two air flushes. Normal furnace burn.
AP11	2/22	No	76	None	No	None	No	Normal fracture. Increased deact conveyor speed. Two O/KMs hung up in tilt table discharge tubes. Disloged when table was tilted up. Normal furnace burn. One M100 detonator (S&A) and two gas generators did not deactivate.
AP12	2/22	No	86	None	Yes	None	Yes	Reduce deactivation conveyor speed back to AP1-AP10 value. Normal fracture and furnace burn.

Table 7
(continued)

Test no.	Test date	Air flush reqd?	Press fracture force (tons)	No. of O/KMs broken during fracture	Pop during O/KM assessing?	No. of large pops during furnace burn	Energetics deactivated (S&A,GG)?	Comments
AP13	2/23	Yes	86	None	No	1	Yes	Normal fracture. Air flush removed piece of overlay on tilt table. Normal furnace burn.
AP14	2/23	No	77	None	No	1	Yes	Normal fracture. An O/KM hung up in a tilt table discharge tube after fracture. Dislodged when table was tilted up. Normal furnace burn.
AP15	2/23	Yes	75	1	No	None	Yes	Normal fracture. Multiple air flushes failed to remove debris stuck on two tooling die holes. This debris was removed by cycling the press. Normal furnace burn.
AP16	2/23	No	73	None	No	None	Yes	Normal fracture and furnace burn.
AP17	2/23	No	73	None	No	None	Yes	Normal fracture and furnace burn.
AP18	2/23	Yes	81	None	Yes	None	Yes	Normal fracture. In two locations, a piece of debris on the tilt table was connected by a wire to another piece of debris down in a die hole. Air flush and a second press cycle would not remove. Six inert mines were loaded into a transport fixture and placed on the tooling. This placement on the tool set severed the interconnecting wire at one location. At the other location, the interconnecting wire was not severed and the inert mine being placed in that location appeared to be slightly mispositioned. Normal furnace burn.
AP19	2/23	Yes	77	None	Yes	1	Yes	Normal fracture. Multiple air flushes failed to dislodge an O/KM hung up in a tilt table discharge tube. Dislodged by cycling the press. Accessing of this warmed up O/KM was poor with a resultant large pop in the furnace.
AP20	2/23	No	76	None	No	None	Yes	Normal fracture and furnace burn.
AP21	2/24	No	82	None	No	None	Yes	Normal fracture and furnace burn. Replaced deac conveyor cover prior to test. Underside of used cover was white in the area above the coil and blackened by soot in the areas away from the coil.

Table 7
(continued)

Test no.	Test date	Air flush reqd?	Press fracture force (tons)	No. of O/KMs broken during fracture	Pop during O/KM assessing?	No. of large pops during furnace burn	Energetics deactivated (S&A,GG)?	Comments
AP22	2/24	No	78	None	No	2	Yes	Normal fracture and furnace burn. Shuttle box conveyor drive motor chain broke after dump.
AP23	2/24	No	74	None	No	1	Yes	Normal fracture. One O/KM hung up in shuttle box; a second dump, a second accessing cycle, and a third dump did not dislodge. Normal furnace burn.
AP24	2/4	Yes	75	None	No	None	Yes	Normal fracture and furnace burn. O/KM from AP24 remained hung up in the shuttle box after dump.
AP25	2/24	No	80	None	No	None	Yes	Normal fracture. Two O/KMs hung up in shuttle box after dump (one from AP24). Normal furnace burn.
AP26	2/24	No	73	None	No	None	Yes	Normal fracture. Six O/KMs hung up in the shuttle box after dump. All attempts to dislodge failed. Shuttle box was disconnected from the conveyor drive chain and dumped into the furnace. After normal O/KM burn, the shuttle box was retrieved from the furnace and reattached to the conveyor drive chain.
AP27	2/25	No	74	1	No	None	Yes	Discharge tubes removed from tilt table prior to test. Normal fracture and furnace burn.
AP28	2/25	Yes	78	None	No	None	Yes	Overlay half hung up in a tooling die hole. Air flush with tilt table up would not remove. Overlay was removed by a press cycle following an air flush with the tilt table down.
AP29	2/25	Yes	85	None	No	2	Yes	Normal fracture and furnace burn.
AP30	2/25	No	83	None	No	1	Yes	Normal fracture and furnace burn.
AP31	2/25	Yes	77	1	No	None	Yes	Normal fracture and furnace burn.
AP32	2/25	No	75	None	Yes	None	Yes	Normal fracture and furnace burn.
AP33	2/25	No	86	None	No	1	Yes	Normal fracture and furnace burn.
AP34	2/25	Yes	81	None	No	1	Yes	Normal fracture. One O/KM hung up in shuttle box after dump; two additional accessing cycles and dumps reqd to remove. Normal furnace burn.

Table 7
(continued)

Test no.	Test date	Air flush reqd?	Press fracture force (tons)	No. of O/KMs broken during fracture	Pop during O/KM assessing?	No. of large pops during furnace burn	Energetics deactivated (S&A,GG)?	Comments
AP35	3/1	No	81	None	No	None	Yes	Added stainless steel insert to bottom of shuttle box and reduced accessing crush height from 1.0 to 0.875 in. Normal fracture and furnace burn.
AP36	3/1	No	78	None	No	None	Yes	Normal fracture and furnace burn.
AP37	3/1	No	75	None	Yes	None	Yes	Normal fracture and furnace burn.
AP38	3/1	No	80	None	No	None	Yes	Normal fracture and furnace burn.
AP39	3/1	No	82	None	Yes	None	Yes	Normal fracture. At least five of the six O/KMs in the shuttle box went high order during accessing. All systems were shut down following the event. Damage was repaired in three days.
AP40	3/8	No	84	None	No	None	Yes	Used heavy duty shuttle box with scalloped bottom. Accessing crush height set to avoid crushing the O/KM detonator column. Normal fracture. Good O/KM accessing. Non-O/KM debris collected for later deactivation. Normal furnace burn.
AP41	3/9	No	73	None	No	None	Yes	Repeat of test AP40. Normal fracture and furnace burn.
AP42	3/9	No	79	None	No	None	Yes	Repeat of test AP40. Normal fracture and furnace burn.
AP43	3/9	No	76	None	No	None	Yes	Same conditions as test AP40 with six mines. Normal fracture and furnace burn.
AP44	3/10	No	82	None	No	None	Yes	Reduced O/KM assessing crush height by 0.125 in. prior to test. Normal fracture. One O/KM hung up in shuttle box after dump; no attempt to dislodge. Normal furnace burn.
AP45	3/10	Yes	80	None	No	1	Yes	Normal fracture. Six O/KMs hung up in shuttle box after dump. One O/KM dislodged by additional accessing cycle and dump. Shuttle box was disconnected from the conveyor drive chain and dumped into the furnace. After normal O/KM burn, the shuttle box was retrieved from the furnace and reattached to the conveyor drive chain.

Table 7
(continued)

Test no.	Test date	Air flush reqd?	Press fracture force (tons)	No. of O/KMs broken during fracture	Pop during O/KM assessing?	No. of large pops during furnace burn	Energetics deactivated (S&A,GG)?	Comments
AP46	3/10	No	75	One	No	2	Yes	Normal fracture. Increased O/KM accessing crush height by 0.125 in. prior to test. One O'KM hung up in shuttle box after dump. A second dump was conducted and, while at the dump station, a pop in the furnace dislodged the O/KM.
AP47	3/10	No	77	None	No	3	Yes	Added a small quantity of fume silica to the shuttle box to attempt to reduce O/KM hang ups. Normal fracture and furnace burn.
AP48	3/10	No	82	2	No	1	Yes	Normal fracture and furnace burn.
AP49	3/10	Yes	85	None	No	3	Yes	Reduced O/KM accessing crush height by 0.125 in. and added fume silica to shuttle box prior to test. Normal fracture. One O/KM hung up in shuttle box after the d ump; dislodged at third dump. Normal furnace burn.
AP50	3/11	Yes	75	None	No	2	Yes	Increased O/KM accessing crush height by 0.125 in. prior to test. Normal fracture. Debris hung up on tooling die hole. Multiple air flushes would not remove. Visual examination showed a piece of debris down in the die hole connected by a wire to another piece of debris on the tilt table. The tilt table was lowered, an air flush was used to move the debris over the die hole, and a press cycle then removed the debris. One O/KM hung up in the shuttle box after initial dump; dislodged by pop in furnace during second dump.
AP51	3/11	Yes	76	None	No	1	Yes	Normal fracture. Small piece of debris hung up on tooling die hole; air flush and a second press cycle did not remove. Only five O/KMs observed in shuttle box after fracture. Normal furnace burn.
AP52	3/11	No	74	None	No	4	Yes	Debris left on tooling after previous test removed by transport fixture with no apparent mine mispositioning. Normal fracture. One O/KM hung up in shuttle box after initial dump was dislodged by a pop in the furnace during a second dump.

Table 7
(continued)

Test no.	Test date	Air flush reqd?	Press fracture force (tons)	No. of O/KMs broken during fracture	Pop during O/KM assessing?	No. of large pops during furnace burn	Energetics deactivated (S&A,GG)?	Comments
AP53	3/11	Yes	81	None	No	2	Yes	Normal fracture. Air flush failed to remove small quantity of debris on tilt table. Seven O/KMs in shuttle box after fracture; one probably from test AP51 that had hung up in the screening conveyor. Normal furnace burn.
AP54	3/11	No	80	1	No	None	Yes	Transport fixture removed debris left on tilt table during previous test. Normal fracture. One O/KM hung up in the screening conveyor. Normal furnace burn.
AP55	3/11	No	79	None	No	None	Yes	Normal fracture. One overlay half hung up in shuttle box; no attempt to remove. Normal burn.
AP56	3/11	No	75	None	No	1	Yes	Normal fracture and furnace burn.
AP57	3/11	Yes	73	None	No	2	Yes	Normal fracture. One O/KM plus overlay half from previous test hung up shuttle box after initial dump; both dislodged by pop in furnace during second dump. Normal furnace burn.
AP58	3/15	No	76	None	No	2	Yes	Normal fracture. One O/KM hung up in shuttle box after initial dump; dislodged by pop in furnace during second dump. Normal furnace burn.
AP59	3/15	No	80	None	No	None	Yes	Normal fracture and furnace burn.
AP60	3/15	No	83	None	No	None	Yes	Normal fracture and furnace burn.
AP61	3/15	No	79	None	No	2	Yes	Normal fracture. Four O/KMs hung up in shuttle box after initial dump; dislodged by pop in furnace during second dump. Normal furnace burn.
AP62	3/15	No	77	1	No	1	Yes	Normal fracture. One O/KM hung up in shuttle box after initial dump; dislodged by pop in furnace during second dump. Normal furnace burn.
AP63	3/15	No	80	None	No	2	Yes	Normal fracture and furnace burn.
AP64	3/15	No	80	1	No	2	Yes	Normal fracture. One O/KM hung up in shuttle box after initial dump; dislodged by pop in furnace during second dump. Normal furnace burn.

NOTES:

(1) All tests used screw type deactivation conveyor.
(2) All tests used the standard (flat, countersunk face) press tooling punch configuration.
(3) The deactivation system induction heater was set at 9.5 kw for all tests.
(4) The open grate furnace below-grate temperature was between 710°F and 943°F for all tests.
(5) All tests used a cryofracture tooling crush height of 0.75 in.
(6) For all tests except test AP11, the deactivation conveyor was set to run for 0.8 sec every 15 sec. For test AP11, the deactivation conveyor was set to run for 0.8 sec every 12 sec.
(7) Tests AP1 and AP40 through AP42 processed single ADAM mines. Test AP2 processed a batch of two ADAM mines. All other tests processed a batch of six ADAM mines.
(8) Mine cool down time in the cryobath varied from 9 min 50 sec to 10 min 5 sec for all tests.
(9) Out-of-cryobath ADAM warm up time varied from 42 sec to 56 sec for all tests.
(10) Tests AP1 through AP39 used a flat bottomed shuttle box. Tests A1P through AP34 used an O/KM crush height of 1.0 in. Tests AP35 through AP39 used an O/KM crush height of 0.875 in. Tests AP40 through AP64 used a scalloped bottom shuttle box.

Table 8 lists the results of the approximations. The average amount of debris associated with the O/KM was estimated to be 6% based on weight measurements. Using the visual estimates, the average epoxy associated with the O/KM was estimated to be 3%. These percentages numbers are subjective in nature and should be only used as approximations.

The amount of debris burned in the deactivation system is the difference between the debris weight before and after deactivation. The amount of epoxy burned during the tests is difficult to estimate because not only does the epoxy burn but also the nylon strings, rubber insulators, piping tubing, and the energetics burn. Again, an estimate of items other than epoxy burned in the deactivation system was made. The average amount of debris burned in the deactivation system was estimated to be 16% while the average epoxy burned in the deactivation was estimated to be 8.5%. These numbers are subjective in nature and should be only used as approximations. Table 9 lists the results of the approximations.

After press punch out, some O/KMs for tests 8, 9, 11, 14, and 19 hung up in the press tooling tilt table discharge tubes. It was determined that the discharge tubes were not required and prior to AP test 27, the tilt table discharge tubes were removed. All subsequent AP tests did not use these discharge tubes and no further problems related to O/KM hang-ups were encountered.

Air flush operations were required after 19 press fracture operations (AP tests 1, 4, 6, 9, 10, 13, 15, 18, 19, 24, 28, 31, 34, 45, 49, 50, 51, 53, and 57) to clean the lower tool set and, after seven press fractures, multiple tilt table and press operations were required for debris removal (AP tests 9, 15, 18, 19, 28, 50, and 51). The scraping mechanism built into the transport fixture also aided in cleaning the tool set and during three tests (AP tests 18, 52, and 54) successfully cleaned the tool set from debris from previous tests.

During AP tests 1 through 26, the shuttle box used a flat bottom plate to support the O/KMs during flat plate accessing. This bottom flat plate was made of A-36 mild steel. Initially, this flat plate worked well with good O/KM accessing and subsequent O/KM debris discharge into the open grate furnace. However, as the test progressed, the plate became gouged and this allowed the O/KMs to stick to the plate during AP tests 23 through 26.

Table 8
Summary of percentage of epoxy associated with O/KMs

Test ID	Debris[a] with bag weight (lb)	Bag weight (lb)	Debris[a] weight (lb)	Non-O/KM items in shuttle box weight (lb)	% of epoxy in shuttle if assumed all is epoxy	Weight of material in shuttle that is not epoxy[e] (lb)	% of epoxy in shuttle
	A	B	C = A-B	$F = K^b - C - J^c$	F / L^d	G	$(F - G) / L^d$
15	4.18	0.05	4.13	0.082	3.17	0.03	2.00
16	4.15	0.05	4.10	0.112	4.32	0.06	2.00
17	4.08	0.06	4.02	0.192	7.41	0.08	4.32
18	4.11	0.06	4.05	0.162	6.25	0.07	3.55
19	4.01	0.06	3.95	0.262	10.12	0.11	5.87
20	4,14	0.06	4.08	0.132	5.09	0.07	2.39
Avg					**6.06**		**3.36**

[a]This debris is the debris to be processed by the deactivation system.
[b]K is the weight of six ADAM mines (5.52 lb).
[c]J is the weight of six O/KMs (1.308 lb). Number determined from TEAD testing.
[d]L is the weight of the amount of epoxy in six ADAM mines (2.59 lb).
[e]This value is an estimate based on visual assessment.

After AP test 26, the shuttle box was inspected and small indentations were noted on the flat plate. These indentations were caused by the O/KM center stainless steel pin being pressed into the flat plate; because of the shape of the O/KM, the majority of the time it sat in the box with the pin in the vertical position. It was decided to switch to a spare shuttle box flat plate insert with the same material characteristics as the previous flat plate insert (A-36) with the hope that this would last for the remainder of the test series. However, after only seven tests, one O/KM was stuck in the shuttle box during AP test 34.

New stainless steel flat plate inserts were installed in the shuttle box to attempt to alleviate the problem. It was decided to try to verify the threshold tolerance of O/KM accessing by reducing the crush height from 1.0 in. to 0.875 in. AP tests 35 through 38 were performed with the stainless steel shuttle box flat plate and the new crush height with good results. During AP test 39, however, at least five of the six O/KMs in the shuttle box went high order during accessing producing only minor damage to the facility. The damage included some severed control cables, broken

Table 9
Summary of percentage of epoxy burned in deactivation system

Test ID	Debris weight before deactivation (lb)	Debris weight after deactivation (lb)	Debris weight burned (lb)	% of epoxy burned if assumed all is epoxy	Weight of material burned that is not epoxy[b] (lb)	% of epoxy estimated burned
	C	H	P = C – H	P / L[a]	Q	(P – Q) / L[a]
15	4.13	3.66	0.47	18.14	0.2	10.42
16	4.10	3.69	0.41	15.83	0.2	8.11
17	4.02	3.52	0.5	19.31	0.2	11.58
18	4.05	3.82	0.23	8.88	0.2	1.16
19	3.95	3.6	0.35	13.51	0.2	5.79
20	4.08	3.52	0.56	21.62	0.2	13.90
Avg				**16.23**		**8.49**

[a]L is the weight of the amount of epoxy in six ADAM mines (2.59 lb).
[b]This value is an estimate based on visual assessment. This includes trip wire threads, wire insulators, plastic manifold and piping, battery, and energetics.

shuttle box drive chains, several cracks in the cryofracture press polypropylene discharge chute, a tripod-mounted camera, a light bulb, and some of the facilities sheet-metal wall panels. None of the test related equipment (accessing press, accessing tooling, conveyors, deactivation system, or debris collection system) was damaged.

The O/KM accessing method was changed from using a flat plate bottom to a scallop on the bottom of the shuttle box. The scallop configuration allowed the accessing force to be applied directly to the KM sphere instead of to the stainless steel center detonator assembly. New inserts were designed and fabricated using heat-treating to bring the scallops to a hardness of RC 58. Safety reviews were organized at WDTC and procedures were re-reviewed and modified. Safety and operational site visits were performed at the site. The final results by WDTC safety were favorable and the cryofracture facility was again readied for live cryofracture operations.

Prior to resuming ADAM AP tests, six inert YPG ADAM QA mines were processed through the entire cryofracture and separation/deactivation system to verify proper equipment and control system operation. All aspects of the process worked well and it was decided to continue with ADAM AP live mines.

AP tests 40 through 42 were performed with single mines to test the new shuttle box scalloped insert accessing function. On-site visual inspections were made prior to and after accessing operations to determine the effectiveness of the O/KM accessing. The O/KMs from these three tests showed no evidence of force applied to the center stainless steel detonator. AP test 43 was performed with six mines to verify that the results from the previous three tests were valid with six O/KMs accessed. All six O/KMs were properly accessed. Since these tests required visual inspections of the O/KMs, it was decided for safety reasons not to operate the debris transport conveyors and the induction heating system. The debris containing the S&A and GG energetics were collected and successfully deactivated at a later time.

The remaining AP test series (tests 44 through 64) were conducted with no further events during accessing. Various O/KM accessing crush heights were tested to verify the best crush with a 0.37-in. crush used for the last 15 tests (AP tests 50 through 64).

During AP tests 44 through 64, O/KMs were still sticking to the shuttle box scalloped plate. Unlike the cause of the previous sticking problems encountered during AP tests 1 through 26, this new problem was caused by the aluminum portion of the O/KM being mashed into the scallops. This occurred 12 times during AP tests 44, 45, 46, 49, 50, 52, 55, 57, 58, 61, 62, and 64. Since the aluminum was mashed into the scallops, to resolve this problem required some type of mechanism to "rap" or impact the shuttle box. It was determined that if there were any stuck aluminum overlays in the shuttle box, the shuttle box would be returned (referred to as the second dump) to the open grate furnace. Any type of pop from the furnace would shake the stuck aluminum overlay off of the shuttle box scallops. For the MCAAP MCDF design, the positive feed system will solve this problem by coming to an abrupt stop (impact shock) during the rotary kiln system (RKS) APE-1236 insertion and dump phase.

Figure 29 is a picture of the Prab robot inserting a munition transport fixture with six ADAM mines into the cryobath. Figure 30 is a picture with a munition transport fixture depositing six cryo-cooled ADAM mines accurately onto the ADAM mine cryofracture press tooling. After the munitions were deposited on the tooling (fig. 31), the Prab robot removed the fixture from the press and returned the fixture to the staging area.

Figure 29
Prab robot inserting transport fixture into cryobath

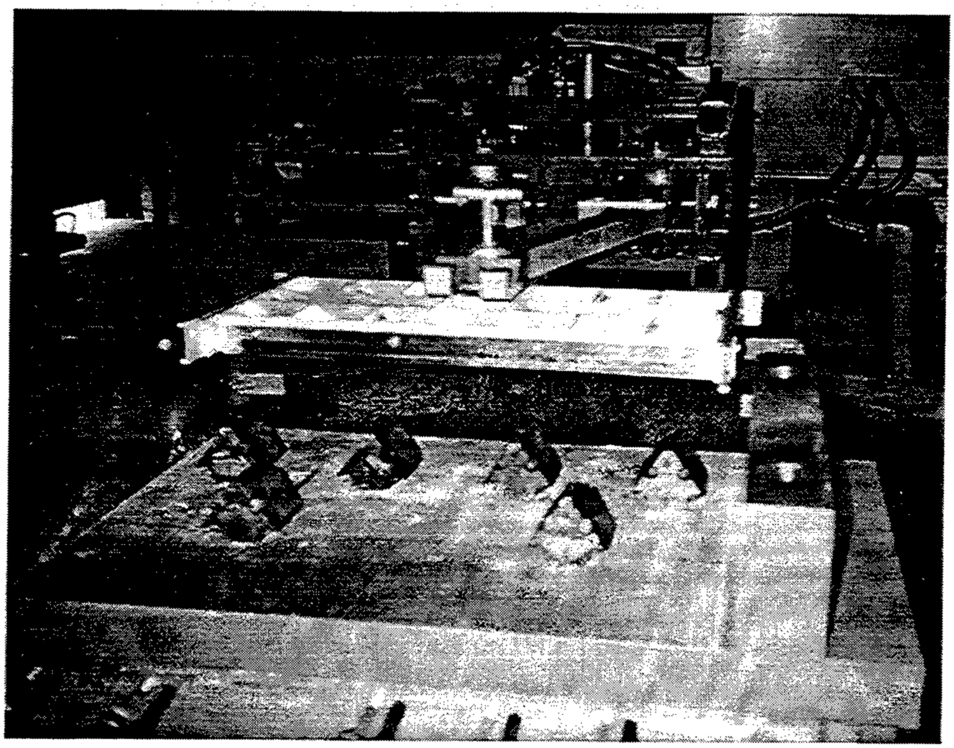


Figure 30
Transport fixture in cryofracture press

Figure 31
ADAM mines on press tooling

The cryofracture press was cycled to punch out the O/KM's and crush the mine body debris. Figure 32 is a picture of the remaining cryofractured debris on the press tooling. The press tilt table dumped the mine debris (fig. 33) into the debris discharge chute where it was deactivated by the induction heater. The tilt table was restored to its normal position (fig. 34) in preparation for the next cryofracture event. The air flush nozzles were used to clean off the lower press tooling (if required). The mine debris was discharged from the debris deactivation system (fig. 35) into small containment bins (fig. 36).

The punched-out O/KMs are discharged onto a vibratory screen conveyor (fig. 37) and then into the shuttle box on the shuttle box conveyor (fig. 38). The vibrating screen conveyor removed epoxy debris associated with the O/KMs. The shuttle box (fig. 39) transports the O/KMs to the O/KM accessing press (fig. 40). After accessing, the shuttle box conveyor transports the accessed O/KMs to the open grate furnace where they are incinerated (fig. 41).

All deactivated debris was transferred from the small containment bins to rectangular metallic sheets (fig. 42) to examine the debris to verify deactivation. Once verified, the debris was poured into drums identified as potential hazardous waste. After completion of the ADAM mine test program, these drums were shipped to Handy & Harmon (a metals recycling firm) for precious metal economic recovery analysis.

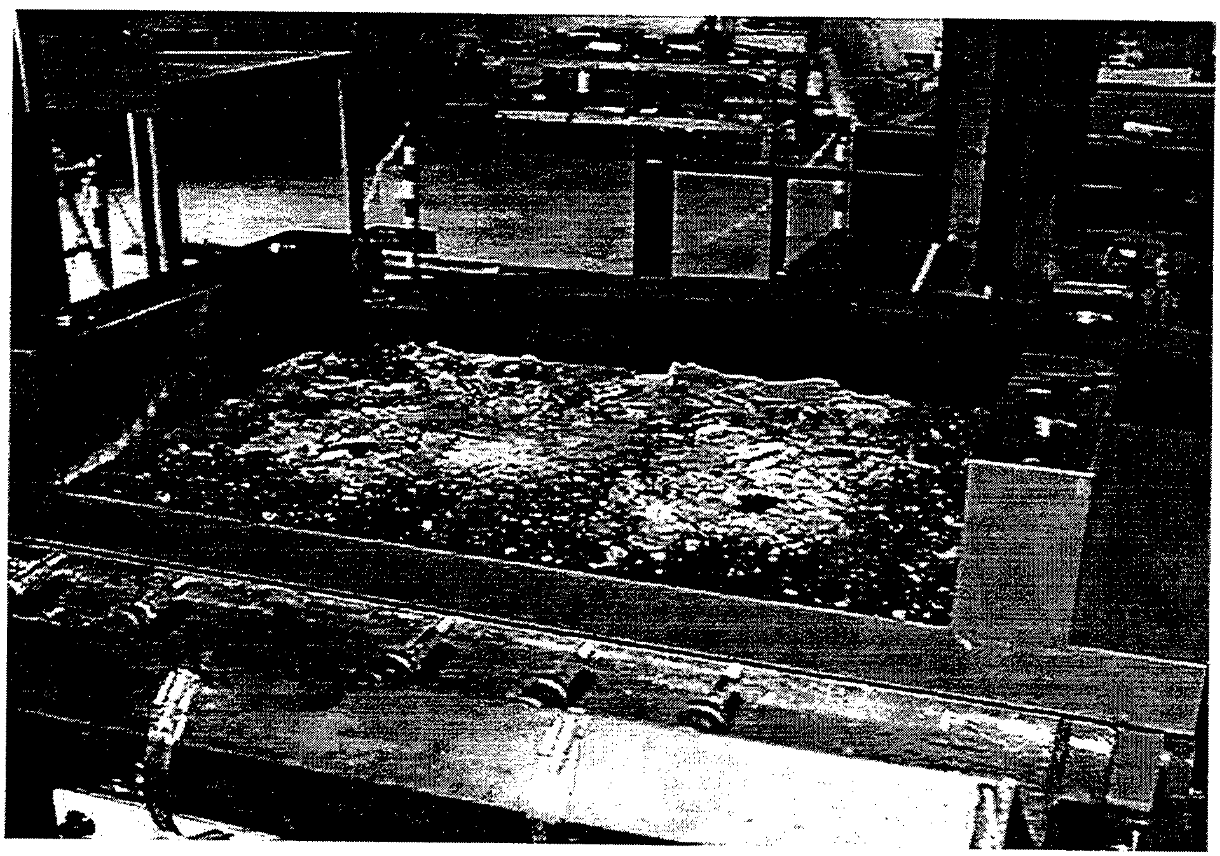


Figure 32
Cryofractured ADAM mine debris on press tooling

Figure 33
ADAM mine press tool set tilt table operation

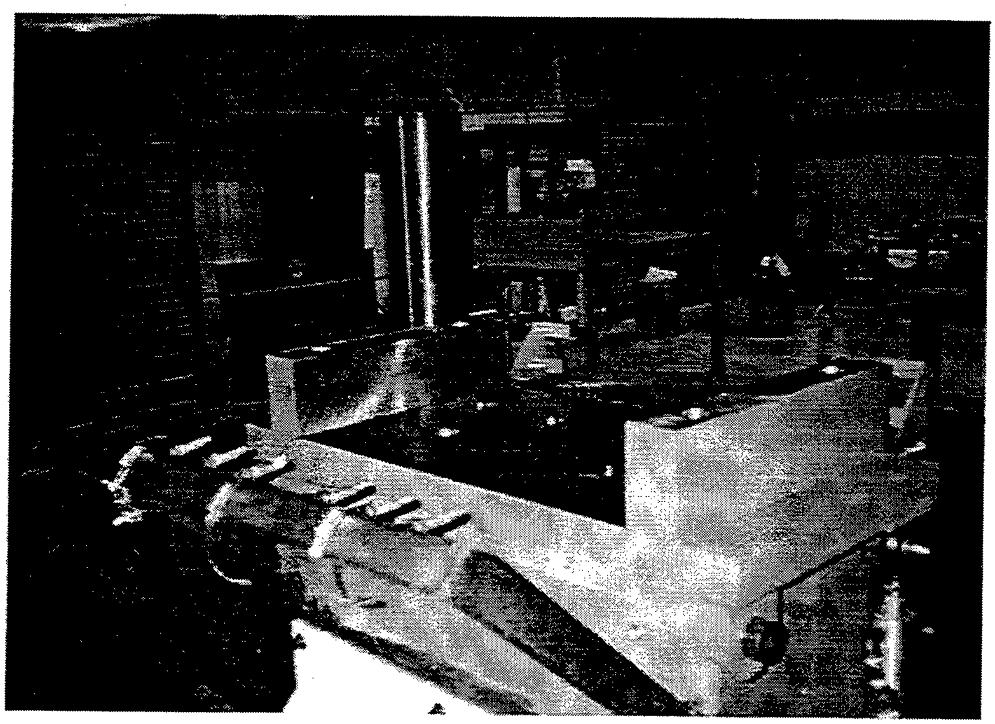


Figure 34
ADAM mine press tool set clear and ready for next cryofracture

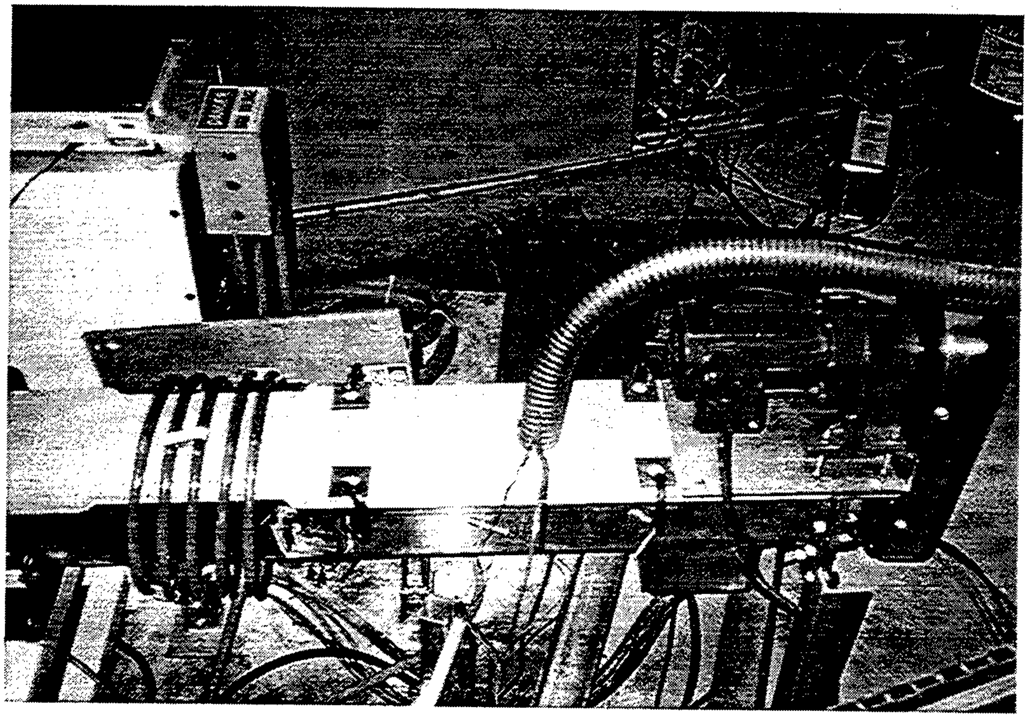


Figure 35
Debris deactivation system

Figure 36
Deactivated debris collection bins

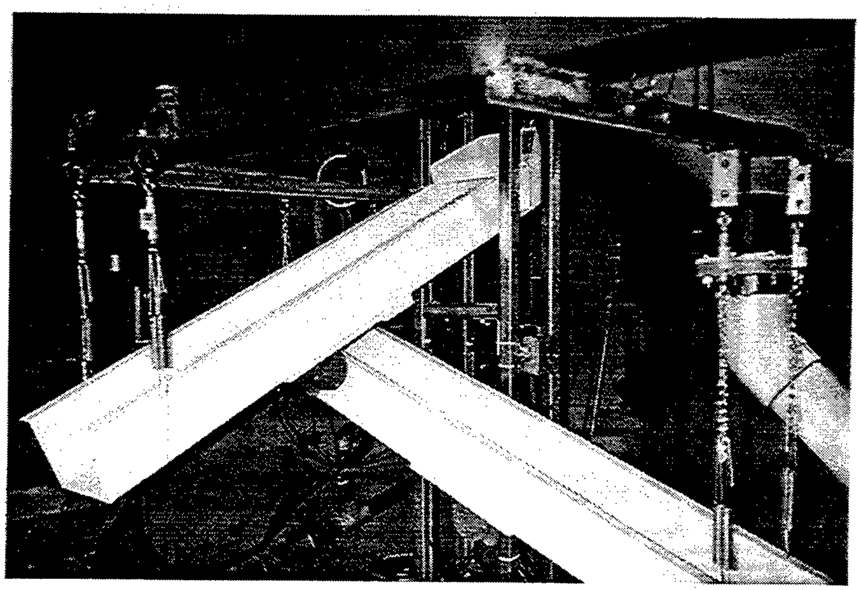


Figure 37
O/KM debris discharge removal screening conveyor

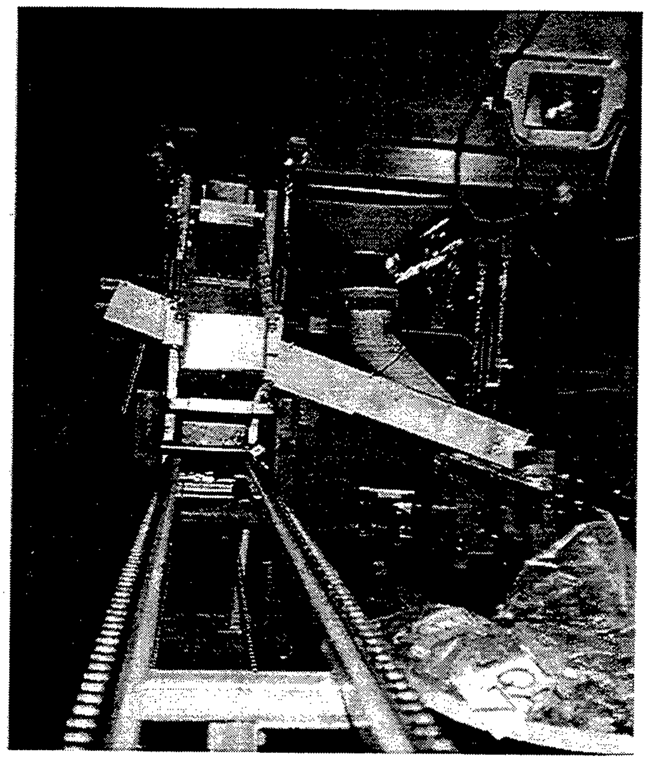


Figure 38
Shuttle box conveyor

Figure 39
Shuttle box with O/KMs

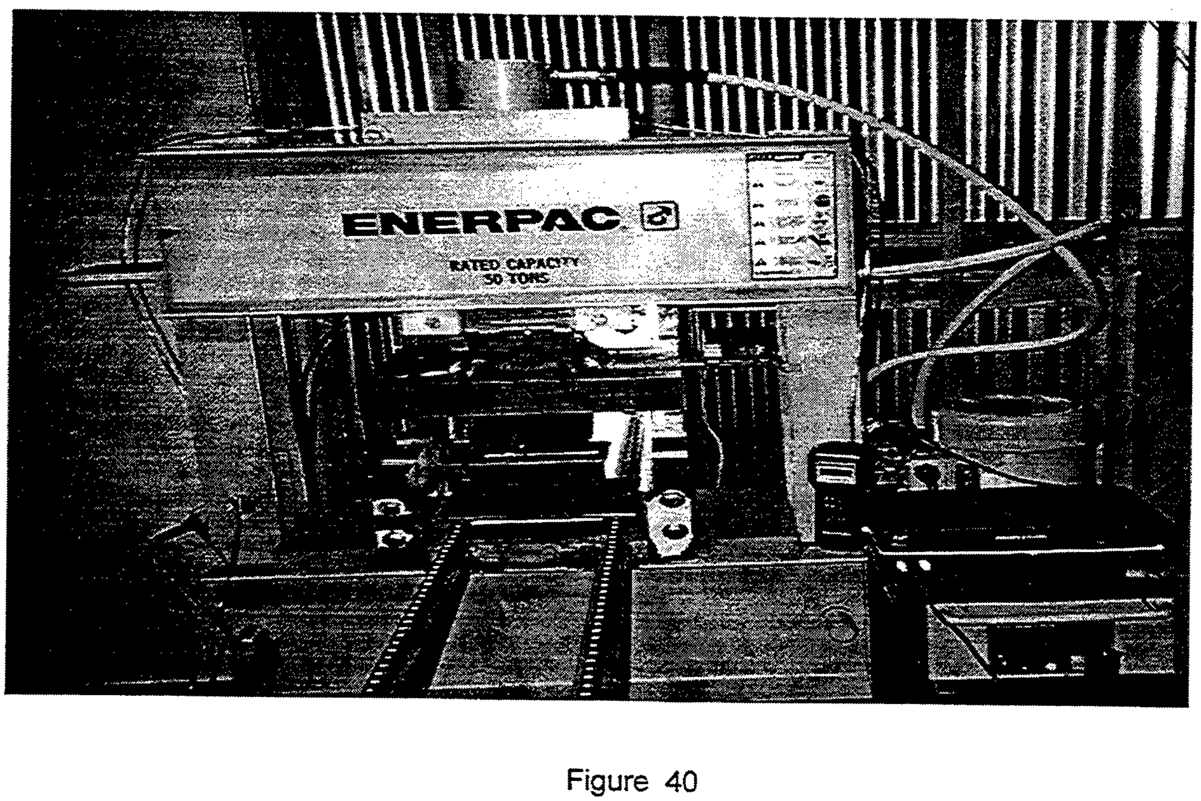


Figure 40
O/KM accessing press

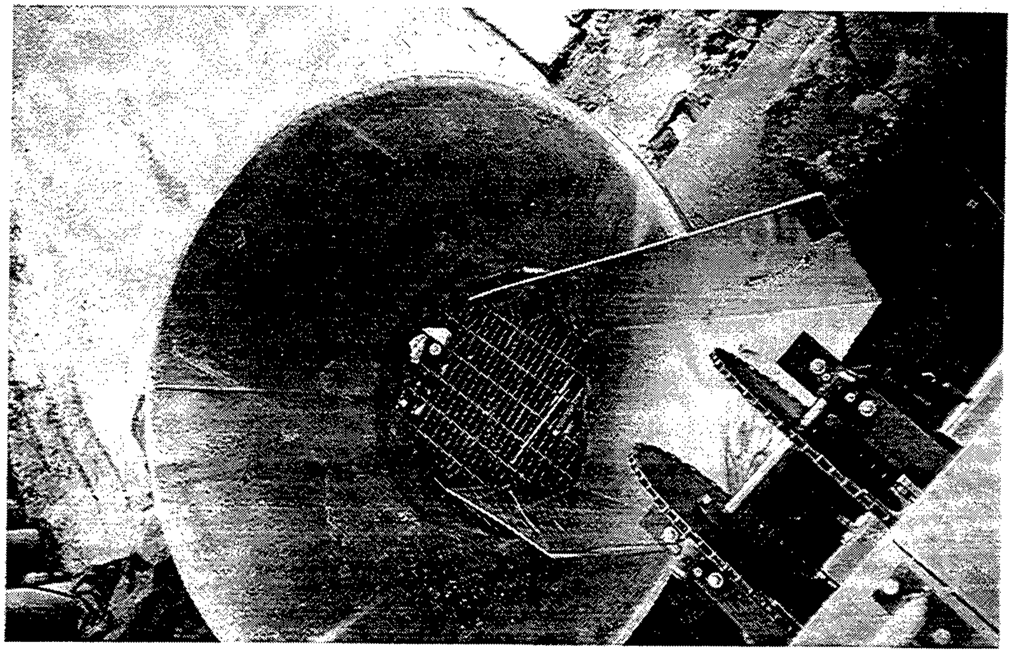


Figure 41
Open grate furnace

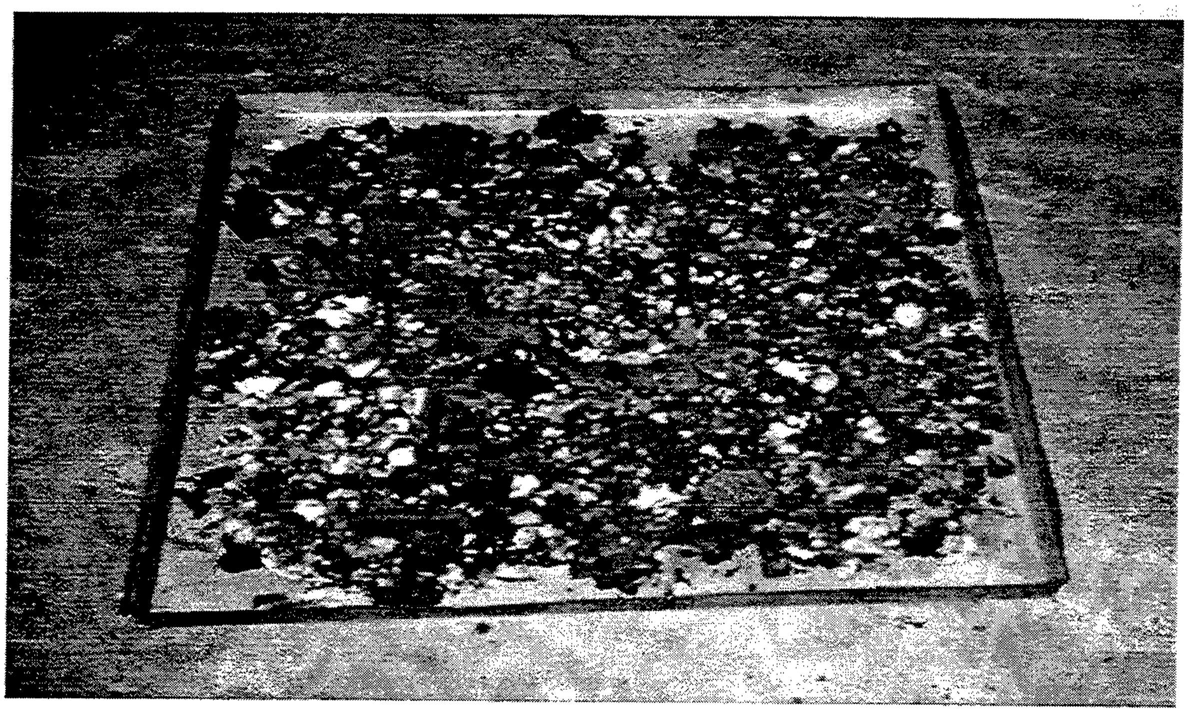


Figure 42
Deactivated debris analysis tray

Rockeye II MK 118 AT Bomblets

Inert Rockeye II Bomblets

A series of 11 cryofracture tests was performed on inert Rockeye II MK 118 bomblets. All tests used the flat plate tooling and horizontally oriented bomblets. Two versions of the inert bomblet were cryofractured, one with a solid cast iron body and the other with the same thin shell body as the explosively loaded bomblet. The test results showed that flat plate crushing of cryo-cooled bomblets provided excellent breakup of the metal components, accessing of the explosive cavity, and separation of the fuze from the booster and primary explosive. These results were obtained with crush heights that did not impose severe crushing forces on the bomblet fuze, thus minimizing the potential for explosions during the fracture.

The Rockeye II bomblets were manually loaded into the cryobath and then manually removed from the cryobath and placed on the press tooling. An expanded metal basket was used for placement of the bomblet(s) in the cryobath. Each bomblet was placed on the press tooling so as to avoid existing indentations in the previously used flat plate surfaces. The elapsed time from removal of the bomblet from the cryobath until fracture varied from 37 to 80 sec.

Table 10 summarizes the results of the inert bomblet tests. The inert bomblet testing was handicapped by the availability of only seven bomblets with the thin shell body configuration as found in the explosively configured bomblet. With this very limited number of representative test bomblets, the tests were nevertheless successful in identifying the parameters that produced excellent cryofracture characteristics. It was judged that the cryofracture of the bomblets with a solid cast iron body produced very limited useful information applicable to live bomblet processing. The bomblets for all tests were cooled until no bubbles were given off from the bomblets when submerged in the liquid nitrogen cryobath. It was determined that the bomblet could be fully cooled in approximately 10 min. The press closure spacing for each bomblet test was provided by placing spacer blocks of the desired thickness on the lower tooling.

All tests except Test 8 cryofractured a single bomblet. Test 8 cryofractured four bomblets. Tests 1 through 6 cryofractured each of the two inert bomblet types at each of three different press closure spacings. Tests 7 through 11 then used a selected press closure spacing to explore other variables.

Test 1 cryofractured a thin shell body bomblet using a press closure spacing of 1.75 in. This closure spacing produced a 0.35-in. crush of the bomblet body. Examination of the debris following removal from the tooling showed that good accessing of the primary explosives cavity was obtained and the fuze was separated from the main body. The fin assembly remained intact while pressing a small indentation in the top of the fuze body.

Test 2 was a repeat of test 1, but with a solid cast iron body inert bomblet. Good breakup of the body casting and separation of the fuze from the body were achieved.

Test 3 was a repeat of test 2, but with a 1.5-in. press closure spacing. This closure spacing produced a 0.6-in. crush of the bomblet body. Compared with the results of test 2, this test produced better breakup of the body casting along with breakup of the fin assembly and a cracked fuze body.

Table 10
Test results summary - inert Rockeye II bomblets

Test date	Test no.	Bomblet configuration	Cool down time (min)	Press closure spacing (in.)	Fracture load (tons)	Comments
4/8/97	1	live round type body shell[a]	40	1.75	no data	Good explosives accessing. Fuze separated from body. Small indentation in fuze casing.
4/8/97	2	cast iron body	45	1.75	no data	Good breakup of body casting. Fuze separated from body.
4/8/97	3	cast iron body	188	1.5	63	Excellent breakup of body casting. Fuze separated from body.
4/8/97	4	live round type body shell	274	1.5	<40	Excellent breakup of body casing. Fuze separated from body. Indentation in fuze casing. Cracks on top and bottom of fuze casing.
4/8/97	5	cast iron body	20	1.25	45?	More breakup than Test 3. Fuze separated from body.
4/8/97	6	live round type body shell[a]	29	1.25	no data	Excellent breakup of body casing. Fuze separated from body. Fuze casing broken up.
4/9/97	7	live round type body shell[b]	30	1.5	Inconclusive[c]	Excellent breakup of body casing. Fuze separated from body.
4/9/97	8	4 cast iron body bomblets	20	1.5	137	Excellent breakup of body casting. All four fuzes separated from bodies.
4/9/97	9	live round type body shell[b]	10	1.5	Inconclusive[c]	Excellent breakup of body casing. Fuze separated from body.
4/9/97	10	live round type body shell[b]	10	1.5	63	Repeat of Test 9 conditions. Excellent breakup of body casing. Fuze separated from body. Two splits in fuze casing.
4/9/97	11	live round type body shell[b]	10	1.5	Inconclusive[c]	Repeat of Test 9 conditions. Excellent breakup of body casing. Fuze separated from body. Two splits in fuze casing.

[a]No explosive simulant fill.

[b]With explosive simulant fill.

[c]The cryofracture breakthrough pressure pulse was not clearly detectable from the stop-block pres sure pulse.

Test 4 was a repeat of test 1 (thin shell body bomblet), but with a press closure spacing of 1.5 in. Excellent breakup of the bomblet body shell and separation of the fuze from the body were obtained. The smaller press closure spacing also produced breakup of the fin assembly and cracks at the top and bottom of the fuze body.

Test 5 was a repeat of test 3 (solid body bomblet), but with a press closure spacing of 1.25 in. The smaller press closure spacing produced much greater breakup of the bomblet body, fin assembly, and fuze body.

Test 6 was a repeat of test 4 (thin shell body bomblet), but with a press closure spacing of 1.25 in. The smaller press closure spacing produced much greater breakup of the bomblet body and fin assembly along with breakup of the fuze body as well.

Based on the results of tests 1 through 6, a press closure spacing of 1.5 in. was selected for providing excellent breakup of the bomblet body while minimizing undue force on the fuze. The selected press closure spacing was used for all remaining tests.

In order to more closely simulate the cryofracture of explosively loaded Rockeye II bomblets, it was decided to fill the remaining four thin shell body inert bomblets with an explosive simulant. A 0.25- in. diameter hole was drilled in each body shell and the cavity was filled with expansion cement. The filled bomblets were not cryofractured until the cement had been allowed to harden.

Test 7 was a repeat of test 4 (thin shell body bomblet), but with an explosive simulant filled bomblet. The simulant fill did not affect the production of excellent cryofracture characteristics.

Test 8 was a repeat of test 3, but with four cast iron body bomblets. Results were very similar to those obtained in Test 3.

Test 9 was a repeat of test 7 (thin shell body, explosive simulant filled bomblet), but with a 10 min. cool down time. The bomblet on the press tooling prior to the fracture is shown in figure 43. Figure 44 shows the bomblet debris on the press tooling following the fracture. Results verified the adequacy of a 10 min. cool down time.

Tests 10 and 11 were repeats of test 9 with very similar results. Figure 45 shows the test 11 bomblet debris following removal from the press tooling.

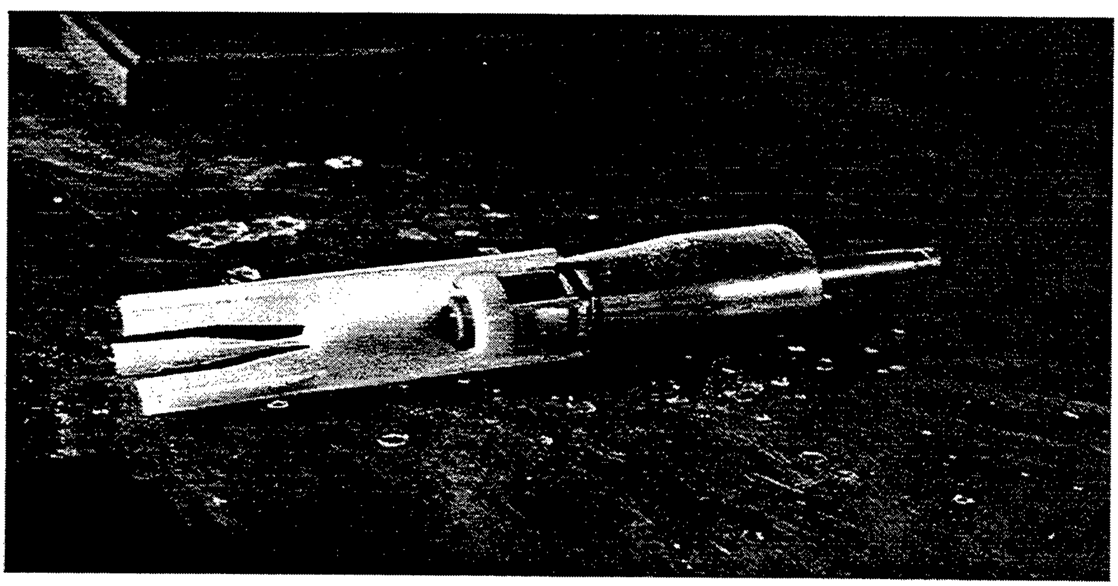


Figure 43
Single inert Rockeye II bomblet on press tooling

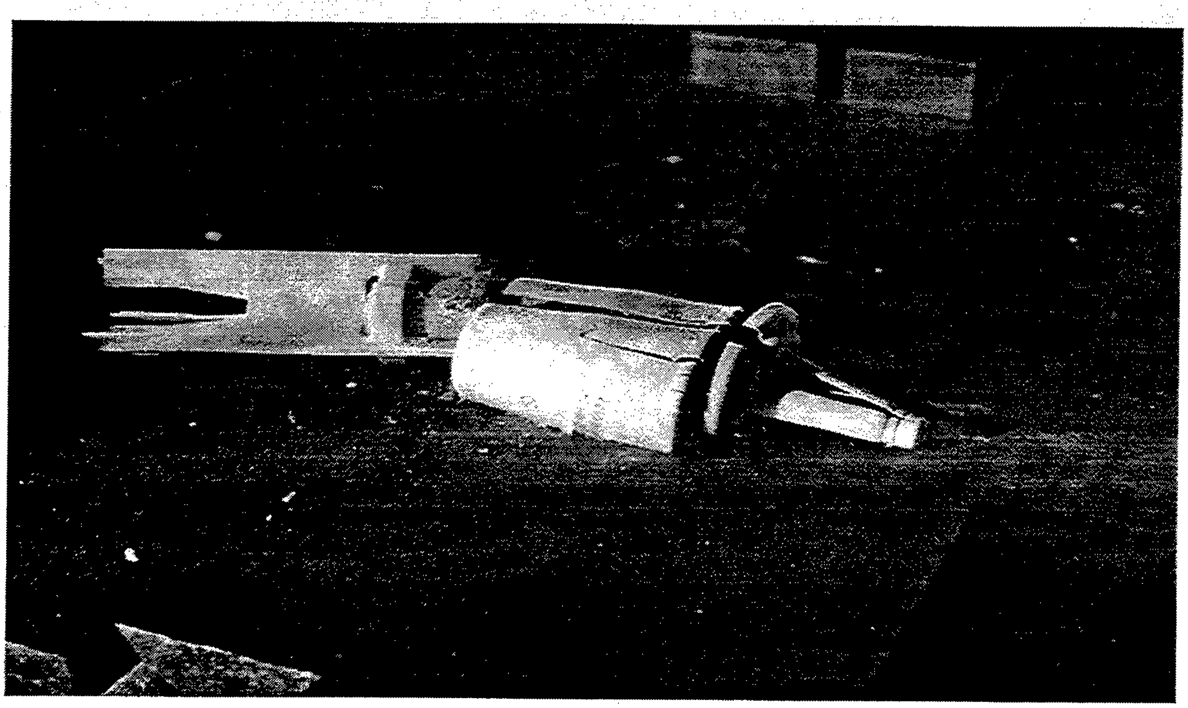


Figure 44
Cryofracture Rockeye II bomblet debris on press tooling

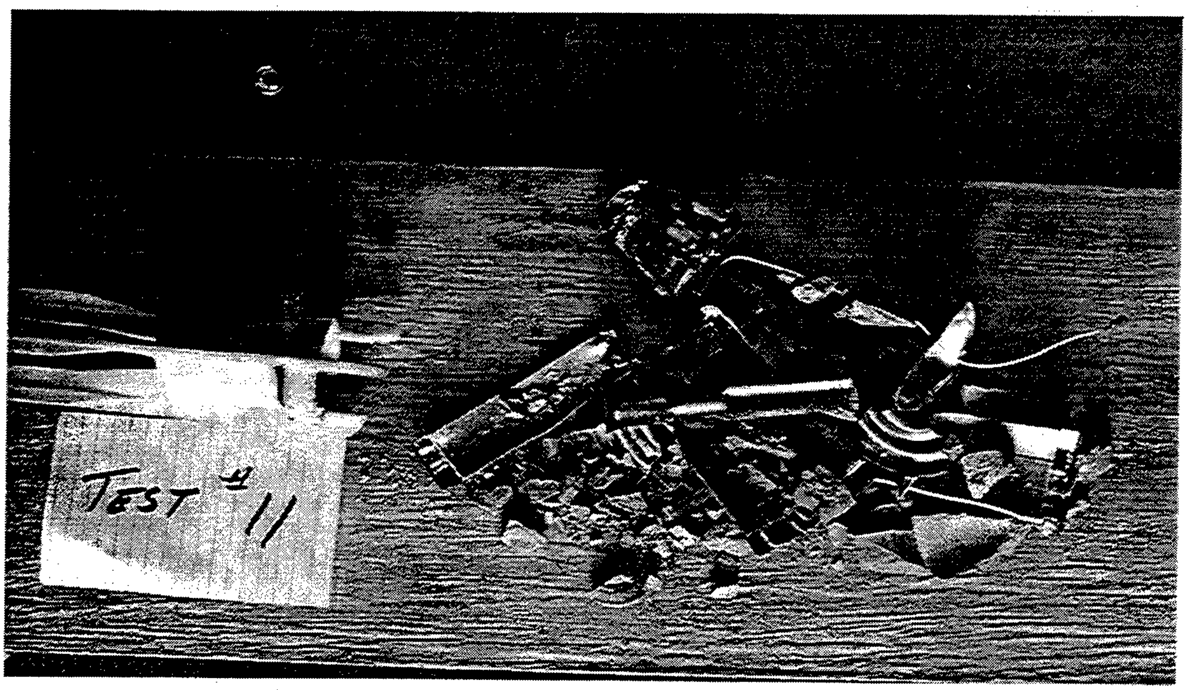


Figure 45
Results of cryofractured Rockeye II debris removed from press for examination

Live Rockeye II Bomblets

Table 11 summarizes the testing of live Rockeye II bomblets. A series of 37 tests (247 bomblets) demonstrated that Rockeye bomblets could be cryocooled, robotically handled, and cryofractured with good explosive accessing and no explosions during the fracture process with repeatable results. The debris from all tests was burned in the open grate furnace that was operated with an average below-grate temperature in the range of 600 to 1000°F. When burned, the functioning of the bomblet detonators could be seen (as flashes) on the CCTV monitor.

All bomblet tests used the same transport fixtures, press tooling, munition orientation and spacing, preset maximum press tonnage force, press closure space, and cool down time. Test 1 was performed with one bomblet to verify the cool down time. Test 2 was performed with four bomblets to verify proper fixture operations. Tests 3 through 37 were performed with seven bomblets with one test (test 29) using four bomblets (end of day). Limited photographs were taken during test 36 due to WDTC safety restrictions. The restrictions concerned personnel around cryocooled live munitions and around exposed explosive material.

Figure 46 shows the Prab robot inserting a munition transport fixture loaded with seven bomblets into the bath. The munitions were retrieved from the cryobath and deposited on the press tooling (fig. 47). Figure 48 shows the results of the flat plate crush of the Rockeye II bomblet. The bomblet body and explosive material have been accessed and are seen in many small pieces. Figure 49 shows the debris in the shuttle box after tooling tilt-table operation. Figure 50 shows the debris in the open grate furnace after shuttle box dumping. Good explosive accessing of the 247 Rockeye II bomblets was accomplished in all 37 tests.

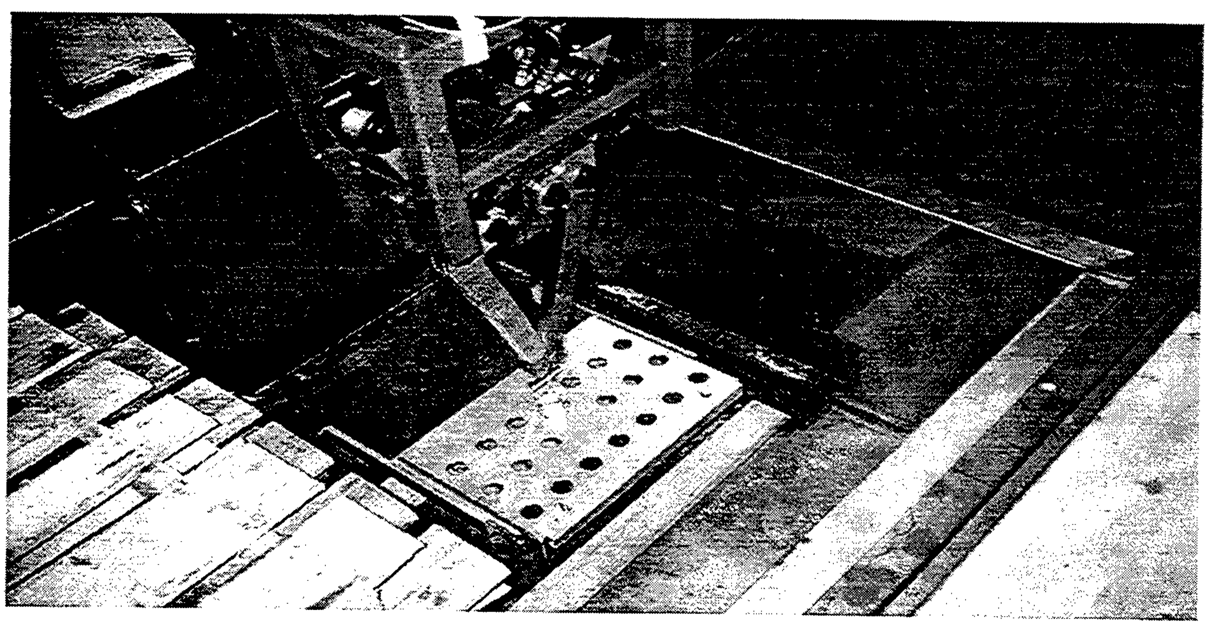


Figure 46
Munition transport fixture with seven Rockeyes in cryobath

Table 11
Test results summary - live Rockeye II bomblets

Test date	Test no.	Number of bomblets	Cool down time (min)	Press closure spacing (in.)	Fracture load (tons)	Comments
3/30/99	1	1	10	1.5	68	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/30/99	2	4	10	1.5	66	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/30/99	3	7	10	1.5	66	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/30/99	4	7	10	1.5	62	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/30/99	5	7	10	1.5	69	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	6	7	10	1.5	59	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	7	7	10	1.5	68	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	8	7	10	1.5	68	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	9	7	10	1.5	67	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	10	7	10	1.5	60	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	11	7	10	1.5	64	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	12	7	10	1.5	70	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	13	7	10	1.5	68	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	14	7	10	1.5	63	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	15	7	10	1.5	68	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	16	7	10	1.5	67	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	17	7	10	1.5	68	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	18	7	10	1.5	60	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	19	7	10	1.5	63	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	20	7	10	1.5	65	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	21	7	10	1.5	69	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	22	7	10	1.5	66	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.

Table 11
(continued)

Test date	Test no.	Number of bomblets	Cool down time (min)	Press closure spacing (in.)	Fracture load (tons)	Comments
3/31/99	23	7	10	1.5	65	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	24	7	10	1.5	62	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	25	7	10	1.5	67	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	26	7	10	1.5	62	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	27	7	10	1.5	62	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	28	7	10	1.5	69	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
3/31/99	29	4	10	1.5	65	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
4/01/99	30	7	10	1.5	66	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
4/01/99	31	7	10	1.5	65	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
4/01/99	32	7	10	1.5	64	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
4/01/99	33	7	10	1.5	62	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
4/01/99	34	7	10	1.5	63	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
4/01/99	35	7	10	1.5	61	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
4/01/99	36	7	10	1.5	61	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.
4/01/99	37	7	10	1.5	64	Excellent breakup of outer casing and internal metal. Excellent detonator accessing.

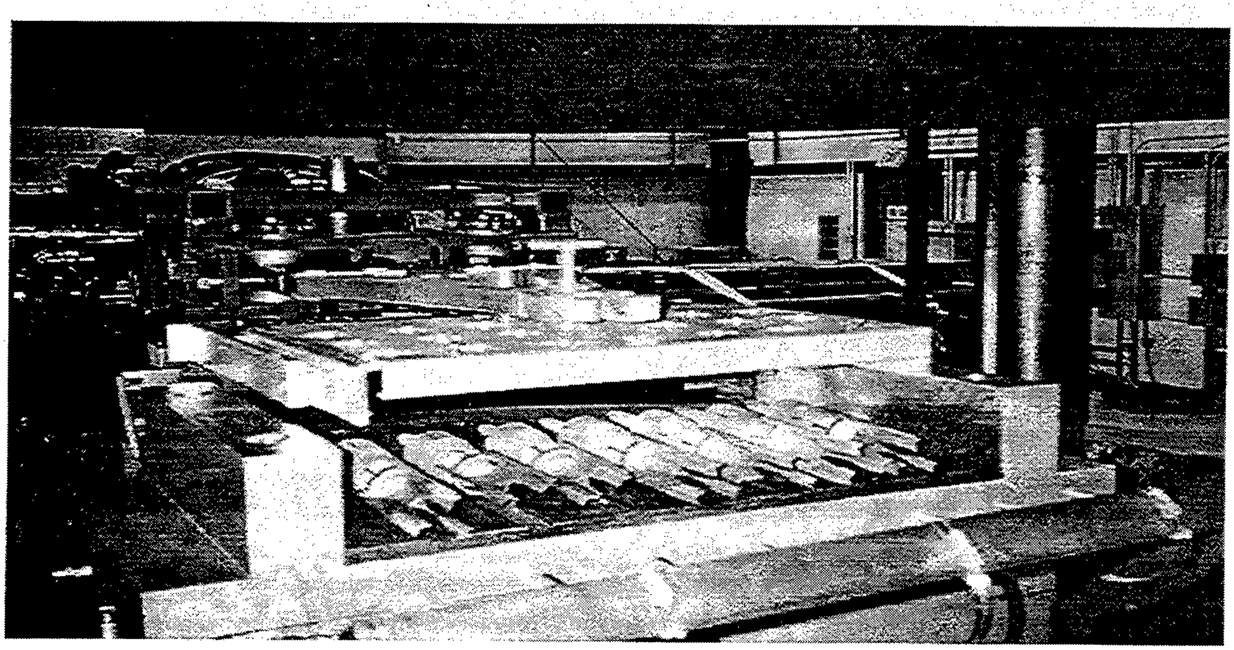


Figure 47
Rockeye II bomblet placement in press

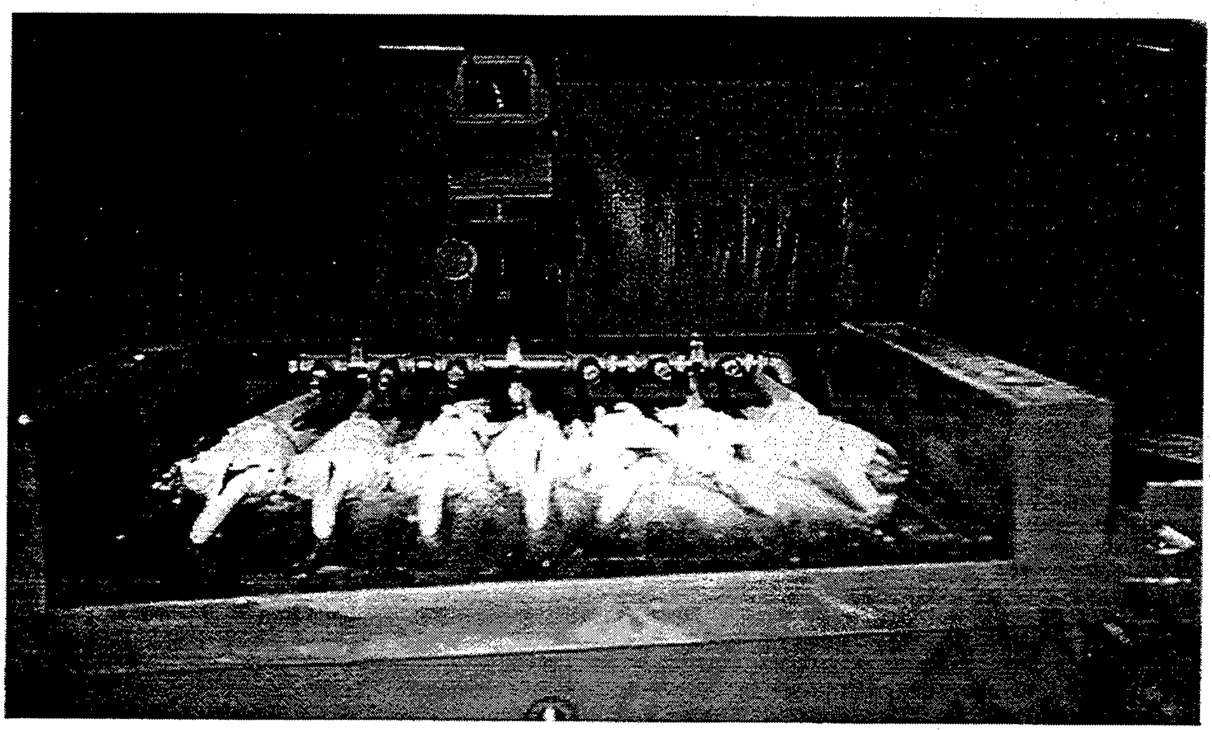


Figure 48
Cryofracture of live Rockeye II bomblets

Figure 49
Shuttle box Rockeye II cryofracture debris

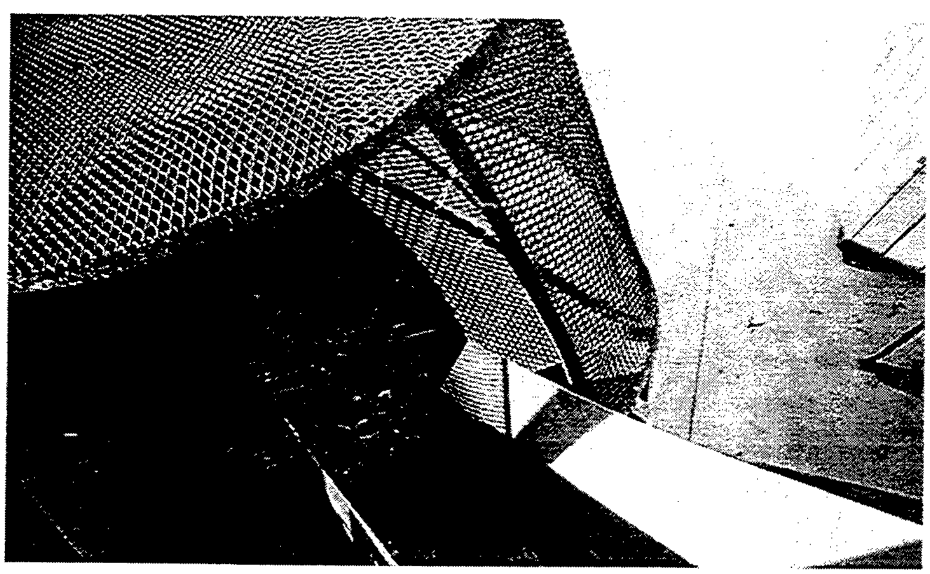


Figure 50
Rockeye II bomblet discharge to open furnace

M16 AP Mines

Inert M16 Mines

A series of six cryofracture tests were performed on inert M16A1 AP mines. All tests used the flat plate tooling originally designed for M23 chemical landmines. Testing with the M16A1 AP mines in both horizontal and vertical orientation were performed. The test results showed that flat plate crushing of vertically oriented mines provided excellent breakup of the metal components and also excellent accessing of the explosive cavities. These results were obtained with crush heights that should not impose severe crushing forces on the explosives, thus avoiding the potential for explosions during the cryofracture.

For all inert tests, the M16A1 mines were manually loaded into the cryobath and then manually removed from the cryobath and placed on the press tooling. Each mine was placed in an expanded metal basket for placement in and removal from the cryobath. Each mine was placed on the press tooling in a location that avoided existing indentations in the flat plate surfaces. The elapsed time from removal of the mine from the cryobath until fracture varied from 38 to 154 sec.

Table 12 summarizes the results of the inert M16A1 AP mine cryofracture tests. While the inert mine testing was severely handicapped by the availability of only four inert mines, the test series was highly successful in that the mine orientation and press closure spacing that produced excellent cryofracture characteristics were identified. The mines for all tests were cooled until no bubbles were produced from the mine while submerged in the liquid nitrogen cryobath. It was determined that the mine could be fully cooled in approximately 70 min.

A major shortcoming of having only four test mines was that it was not possible to reliably determine the maximum press force required to cryofracture this munition. An examination of the fracture load data presented in table 12 shows that, for a vertically oriented mine, the fracture load varied from 72 to 125 tons. Further tests may have expanded this range. The press closure spacing limit for each mine test was provided by placing spacer blocks of the desired thickness on the lower tooling. Within the range of press closure spacings tested, the maximum fracture force for a vertically oriented mine is believed to occur at the initial fracture of the cast iron cylinder and is thus independent of the final press closure spacing. Very small press closure spacings would be expected to produce press loads that are greater than the initial fracture load. The fracture signature was recorded for all tests. On tests 2, 2a, and 2b, the maximum pressing force was less than 40 tons, the lower limit of the measurement capability.

Test 1 was the cryofracture of a vertically oriented mine using a 3.75-in. press closure spacing. This closure spacing resulted in a 1.54-in. crush following contact with the fuze cavity plug in the top of the mine. The inert mine used for this test had been disassembled for examination of the internals and then reassembled. It was judged that this disassembly/reassembly process had little or no effect on the subsequent cryofracture characteristics. Very good breakup of the mine canister and internals was achieved.

Table 12
Test results summary - inert M16A1 AP mines

Test date	Test no.	Mine orientation on tooling	Cool down time (min)	Press closure spacing (in.)	Fracture load (tons)	Purpose of test
4/8/97	1	vertical	92	3.75	105	Good outer canister breakup. Plastic booster cavity intact but open at bottom end.
4/8/97	2	horizontal (plug at 12 o'clock)	115	3.5	<40	Outer canister remained intact. Could not assess internal breakup. Debris left on tooling for another press stroke.
4/8/97	2a	horizontal (plug at 12 o'clock)	115	2.75	<40	Outer canister started to breakup but judged insufficient accessing for furnace burn.
4/8/97	2b	horizontal (plug at 12 o'clock)	115+30	2.0	<40	Recooled debris from Test 3 for 30 min. Excellent internal metal and plastic breakup but uncertain about breakup of outer canister when dumping to furnace. Also concern that severe crushing could cause explosion during fracture.
4/8/97	3	vertical	241	3.0	72	Excellent breakup of outer canister and internal metal and plastic. Excellent booster cavity accessing.
4/8/97	4	vertical	316	3.25	125	Excellent breakup of outer canister and internal metal and plastic. Excellent booster cavity accessing.

Test 2 was the cryofracture of a horizontally oriented mine using a press closure spacing of 3.5 in. This closure spacing resulted in a 0.55-in. crush of the mine. The outer canister remained intact and it was not possible to assess internal breakup. Since the results of this test were clearly unsatisfactory, it was decided to immediately further crush this same mine to see if further breakup could be achieved.

Test 2a crushed the test 2 debris to a press closure spacing of 2.75 in. This closure spacing resulted in a 1.30-in. crush of the mine. The outer canister was still intact, but has started to break open. The fuze cavity plug and its adapter had broken away from the mine body. It was judged that the breakup was not adequate for feed to a furnace and it was decided to re-cool and further crush this same mine to see if greater breakup could be achieved.

Test 2b re-cooled the test 2a debris for approximately 30 min and then crushed this debris to a press closure spacing of 2.0 in. This closure spacing resulted in a 2.05-in. crush of the mine, approximately half of its diameter. Canister breakup was much improved. Excellent breakup of the mine internals, including the booster cavity was achieved. Two concerns were produced by the results of this test:

(1) the outer canister was not broken up as much as desired and there was concern that the internals might not be sufficiently dispersed when the debris was dumped into a furnace and (2) there was concern that the severe crushing involved in the test could produce an explosion of a live mine during the fracture.

Based on the results of tests 2, 2a, and 2b, it was decided that further cryofracture testing of horizontally oriented mines would not be conducted and that the two remaining mines would be used for what appeared to be more promising vertically oriented cryofracture tests.

Test 3 was the cryofracture of a vertically oriented mine using a 3.0-in. press closure spacing. This closure spacing produced a 2.29-in. crush of the mine following contact with the fuze cavity plug in the top of the mine. Examination of the mine debris following removal from the tooling showed that excellent breakup of the canister and internals, including the booster cavity, was achieved.

Test 4 was the cryofracture of a vertically oriented mine using a 3.25-in. press closure spacing. This closure spacing produced a 2.04-in. crush of the mine following contact with the fuze cavity plug in the top of the mine. Figure 51 shows the mine on the press tooling just prior to the fracture. Figure 52 shows the mine debris on the press tooling following the cryofracture. For this test, the debris was swept off the press tooling and allowed to fall into the fragment cart in order to provide an assessment of the dispersion produced by impact with the press discharge chute and the fragment cart. Figure 53 shows the mine debris in the fragment cart. Excellent breakup of the mine canister and internals, including the booster cavity was achieved.

Based on the results of tests 1, 3, and 4 for vertically oriented mines, a press closure spacing of 3.25 in. was selected for live mine testing.

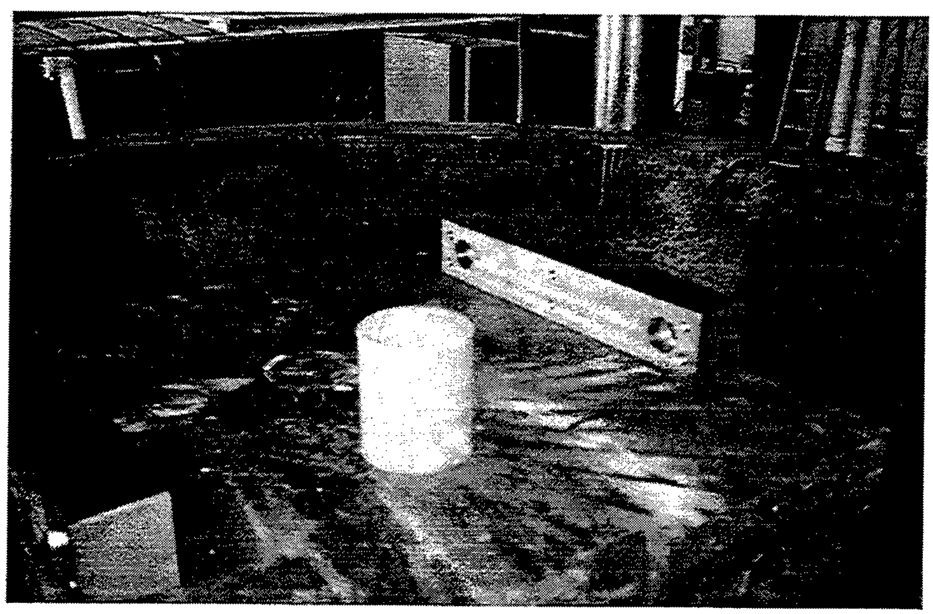


Figure 51
Inert M16A1 mine on press tooling prior to cryofracture

Figure 52
Cryofracture of inert M16A1 mine

Figure 53
Inert M16A1 after discharge to fragment cart

Live M16 Mines

Table 13 summarizes the testing of live M16 mines. A series of 25 tests (61 mines) were performed to demonstrate that M16 mines could be cryocooled, robotically handled, and cryofractured with good explosive accessing and no explosions during the fracture process with repeatable results. The debris from all tests was burned in the open grate furnace that was operated with an average below-grate temperature in the range of 600 to 1000°F. When burned, the functioning of the mine detonators could be seen (as flashes) on the CCTV monitor.

All M16 tests used the same transport fixtures, press tooling, munition orientation and spacing, preset maximum press tonnage force, and press closure space, with the cool down time being the only parameter that required determination. Tests 1 through 7 were performed with one mine per test to establish the cool down time. The time was varied from 60 min to 26 min with 30 min selected as the cool down time. Test 8 and 9 were performed with two mines and tests 9 through 11 were performed with three mines. A large pop occurred in the open grate furnace during test 11. It was decided to run a series of tests with the 45 min cool down time to see if a burn difference in the open grate furnace could be detected. Tests 12 through 18 were performed with three mines using a 45 min cool down time. Tests 19 through 24 ramped the time from 40 min to 30 min. Cool down times greater than 35 min provided improved breakup of the mine but no improvement in burn characteristics were observed. Test 25 repeated the 30 min cool down time. Tests 21, 22, and 24 were performed without the mine fuze plugs inserted to determine if there is an appreciable difference in cryofracture/burn characteristics between mines with and mines without fuze plugs. It was determined that there is no difference. Limited photographs were taken during test 25 since WDTC Safety restricted personnel access to the M16 mines after cryocooling and after fracture due to safety concerns.

Figure 54 shows the results of the flat plate crush of the M16 mines. The mine body and explosive material were accessed and are seen in many small pieces. Figure 55 shows the debris in the shuttle box after tooling tilt-table operation. Figure 56 shows the debris in the open grate furnace after shuttle box dumping. Good explosive accessing of the 61 M16 mines was accomplished in all 25 tests.

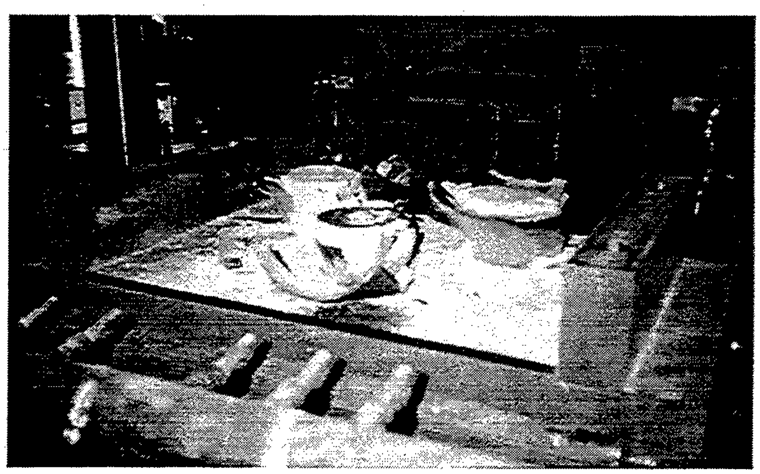


Figure 54
Cryofracture of live M16 mines

Table 13
Test results summary - live M16 AP mines

Test date	Test no.	Number of mines	Cool down time (min)	Press closure spacing (in.)	Fracture load (tons)	Comments
4/6/99	1	1	61	3.25	162	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing.
4/6/99	2	1	48	3.25	155	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing.
4/6/99	3	1	38	3.25	160	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing.
4/7/99	4	1	32	3.25	140	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing.
4/7/99	5	1	26	3.25	152	Good breakup of outer canister and internal metal with some big large pieces. Good booster cavity accessing.
4/7/99	6	1	30	3.25	150	Good breakup of outer canister and internal metal. Good booster cavity accessing.
4/7/99	7	2	30	3.25	267	Good breakup of outer canister and internal metal. Good booster cavity accessing.
4/7/99	8	2	30	3.25	239	Good breakup of outer canister and internal metal. Good booster cavity accessing.
4/7/99	9	3	30	3.25	361	Good breakup of outer canister and internal metal. Good booster cavity accessing.
4/7/99	10	3	30	3.25	392	Good breakup of outer canister and internal metal. Good booster cavity accessing.
4/7/99	11	3	30	3.25	375	Good breakup of outer canister and internal metal. Good booster cavity accessing. Large pop requiring grate and furnace UV detector replacement.
4/12/99	12	3	45	3.25	381	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing.
4/12/99	13	3	45	3.25	365	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing.
4/12/99	14	3	45	3.25	385	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing. Plastic discharge cone was damaged due to wear and tear. Discharge cone repaired.

Table 13
(continued)

Test date	Test no.	Number of mines	Cool down time (min)	Press closure spacing (in.)	Fracture load (tons)	Comments
4/14/99	15	3	45	3.25	370	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing.
4/14/99	16	3	45	3.25	380	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing.
4/14/99	17	3	46	3.25	366	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing. Debris shuttle box broke and was repaired.
4/14/99	18	3	45	3.25	378	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing.
4/14/99	19	3	40	3.25	397	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing.
4/14/99	20	3	39	3.25	377	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing.
4/14/99	21	3	38	3.25	365	Excellent breakup of outer canister and internal metal. Excellent booster cavity accessing. No fuze plugs in mine.
4/15/99	22	3	35	3.25	360	Good breakup of outer canister and internal metal. Good booster cavity accessing. No fuze plugs in mine.
4/15/99	23	3	35	3.25	373	Good breakup of outer canister and internal metal. Good booster cavity accessing.
4/15/99	24	3	30	3.25	379	Good breakup of outer canister and internal metal. Good booster cavity accessing. No fuze plugs in mine.
4/15/99	25	3	30	3.25	370	Good breakup of outer canister and internal metal. Good booster cavity accessing. Limited photographs of test.

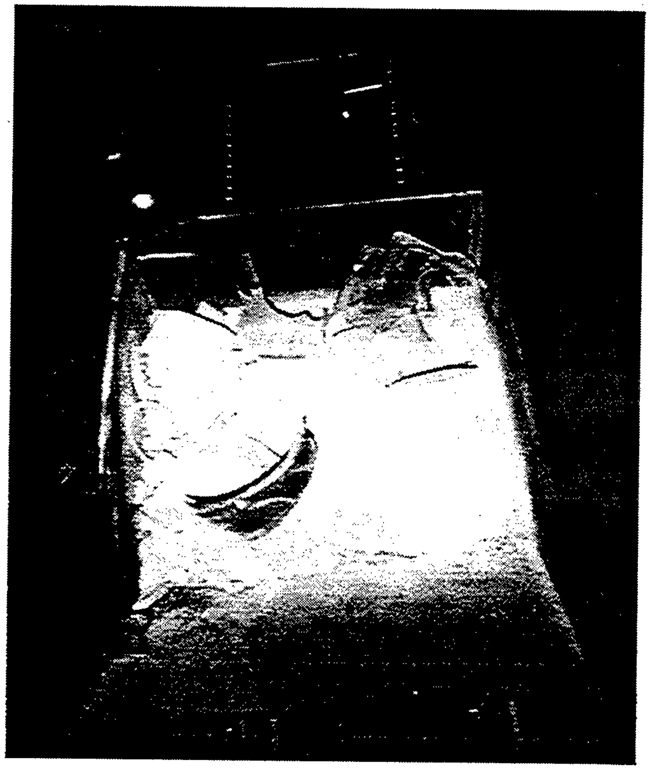


Figure 55
M16 mine cryofracture debris in shuttle box

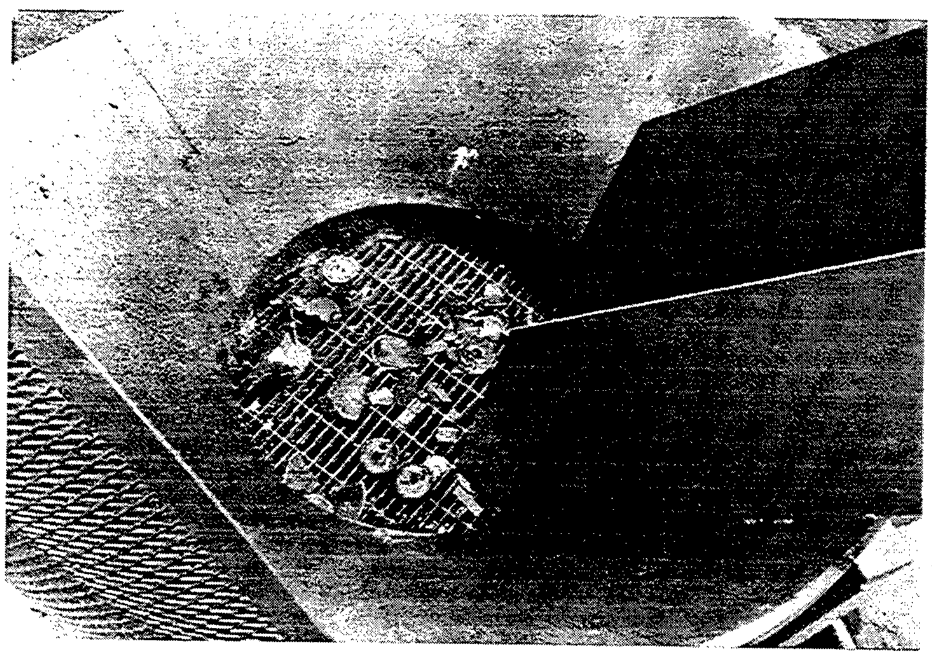


Figure 56
M16 mine discharge to open grate furnace

Inert M483A1 155-mm Projectiles

A series of 11 cryofractures was performed on inert M483A1 projectiles and segments of projectiles. Two press tooling configurations were used in an effort to not only breakup the projectile body, but also to fracture the M42 and M46 submunition grenades contained within the projectile body and to access the expulsion charge cavity in the nose of the projectile. The first tool set was shaped to closely confine the projectile body and submunition grenades following the fracture. The second tool set was comprised of upper and lower flat plates. The results of the tests showed that, within the 750 ton capacity of the test facility press, neither tool set provided the necessary breakup of the projectile body and all of the submunition grenades.

Tests using the shaped tooling configuration showed that the projectile body and submunition grenades were excessively confined following the fracture of the body and the press had insufficient capacity to break up all the submunition grenades. For a full-up M483A1 containing 88 submunition grenades, the 750 ton press was able to close only 1.24 in. following contact with the projectile body. This "crushing distance" was insufficient to provide adequate breakup of the projectile body and to access the expulsion charge cavity in the nose of the projectile and all of the submunition grenades. It was observed that large pieces of the projectile body bridged across the lower tooling cavity following initial fracture and the press force was primarily applied through the body pieces into the tooling instead of into the submunition grenades.

Tests using the flat-plate tooling configuration showed that the projectile body and submunition grenades were insufficiently confined following the fracture of the body, in this ~~tooling configuration.~~ This allowed unaccessed submunition grenades to be ejected from the tooling during the fracture. The flat plate tooling did allow much greater crushing before the press capacity was reached. A full-up M483A1 was crushed 4.7 in. following contact with the projectile body. This added crushing provided good breakup of the projectile body but it was still insufficient to access all of the submunition grenades that were not ejected from the tooling.

The press was configured to provide its maximum capacity for all M483A1 tests. Only a small portion of the cryobath was used for the M483A1 tests. The unused portion of the cryobath was filled with foamboard in order to minimize the use of liquid nitrogen (fig. 57). A fixture for holding the M483A1 projectiles in the cryobath was fabricated from 2 x 4 and 2 x 6 lumber (fig. 58). The projectiles were loaded into and removed from the cryobath with nylon slings and a forklift (fig. 59). After removal from the cryobath, the projectile was manually removed from the lifting sling and placed on closely spaced forklift tines for transport to the press tooling. A wood fixture was fabricated to facilitate movement of the projectile from the forklift tines into the press tooling. Axial positioning on the tooling was determined prior to the test using an uncooled projectile. The elapsed time from removal of the projectile from the cryobath until fracture varied from 2 to 3.5 min.

For all tests, the press closure spacing was determined by placing 1.5-in. diameter copper tubing crush specimens (two minimum) on the lower tooling prior to the fracture. These specimens were then crushed during the fracture and their average measured height after the fracture was used to calculate the test closure spacing.

Table 14 summarizes the results of the inert M483A1 cryofracture tests. The munitions for all tests were cooled until no bubbles were given off by the munition when submerged in the liquid nitrogen cryobath. It was determined that the full-up M483A1 projectile with 88 submunition grenades required approximately 4 hrs to fully cool.

For most of the tests, each of the eight columns of submunition grenades within the projectile body were painted a specific color so that the location of regions of good or poor grenade accessing could be identified during examination of the cryofractured debris. For all tests, the munition was placed on the press tooling with the internal keyslot in the 6 o'clock position.

The maximum pressing force for tests 1 and 2 was obtained from a visual observation of the local tonnage gage. Starting with Test 3, control system software was installed to provide a computerized readout of the entire fracture signature, i.e., pressing force versus time.

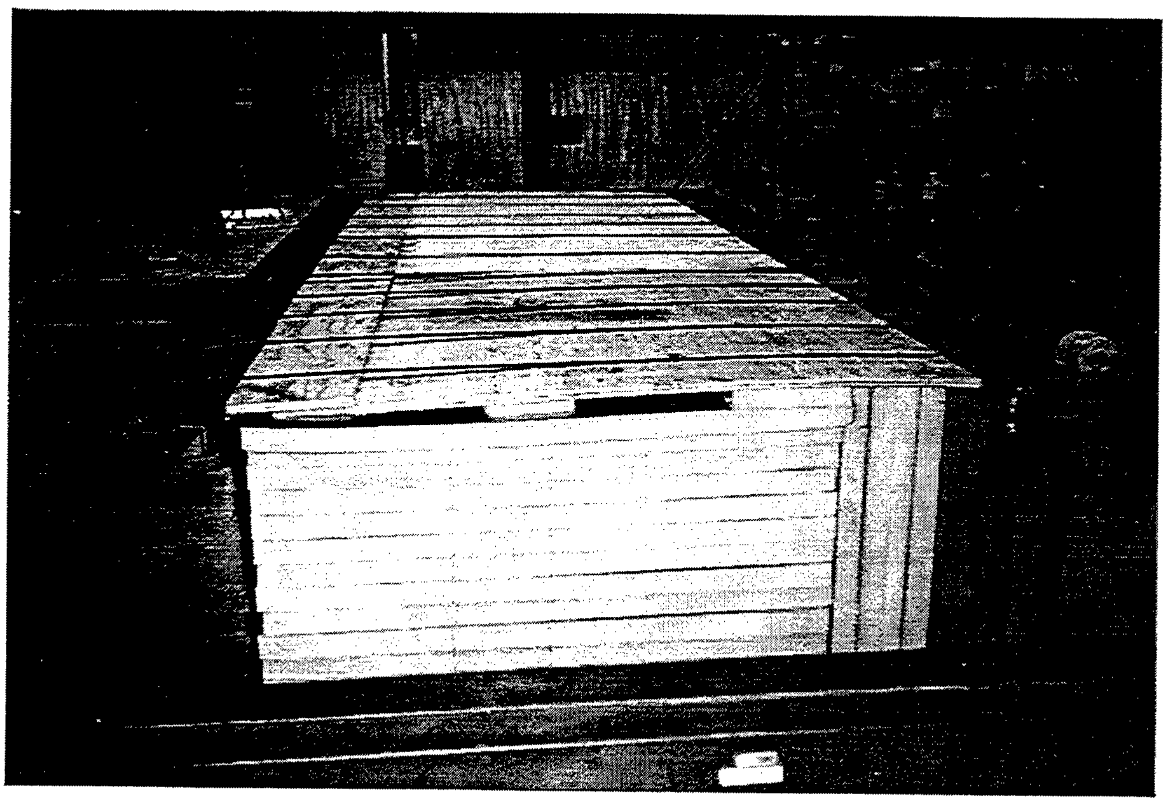


Figure 57
Cryobath with foamboard for M483A1 projectile tests

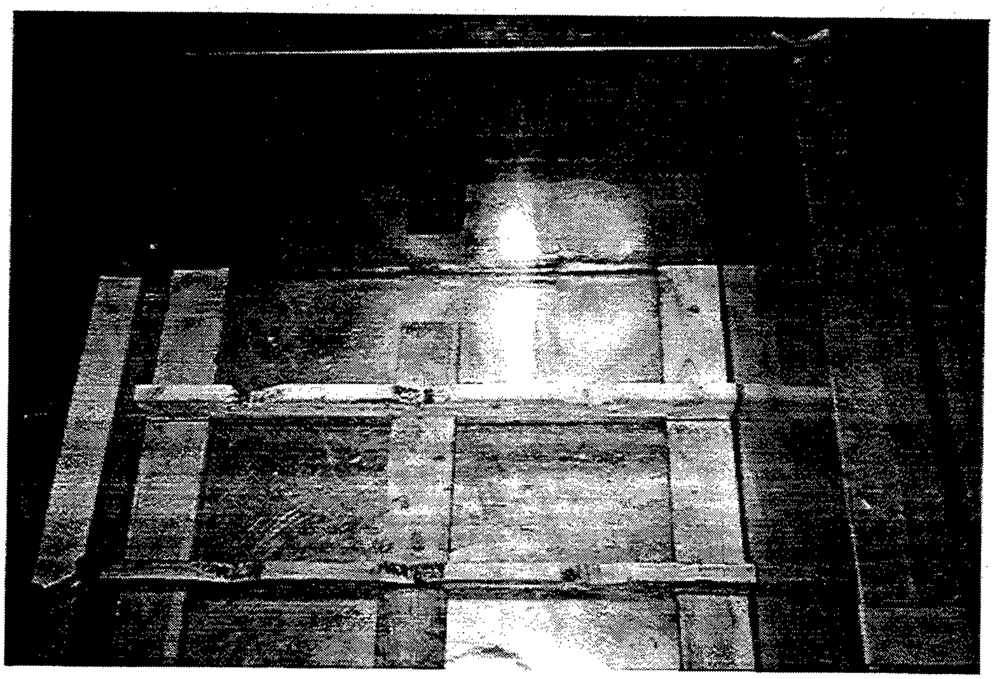


Figure 58
M483A1 projectile holder in cryobath

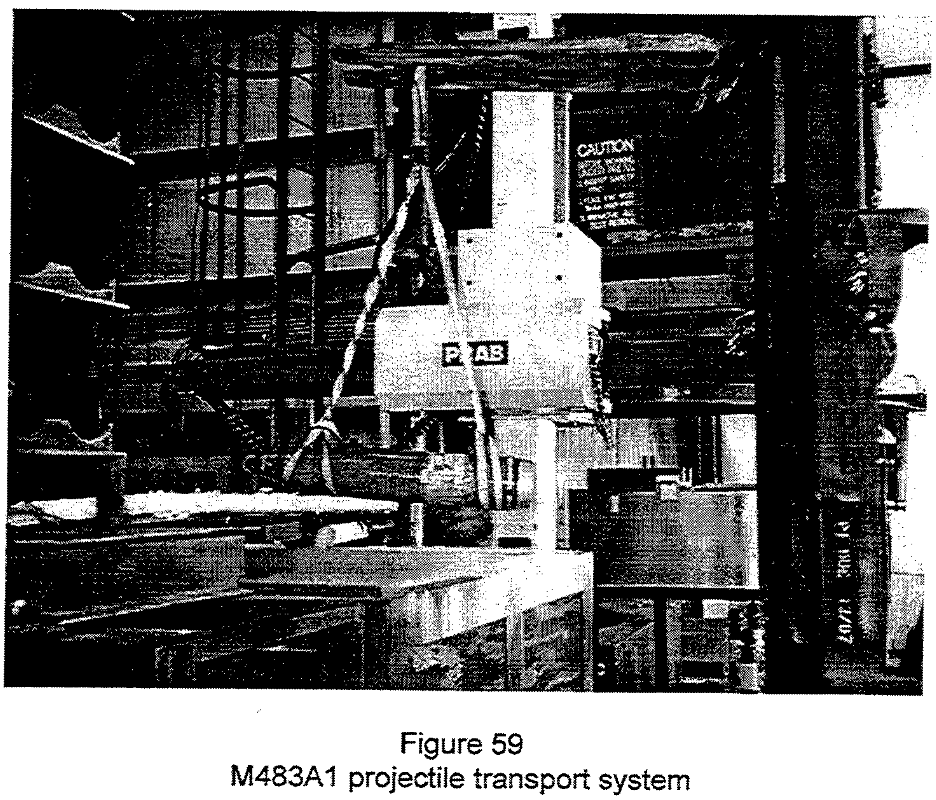


Figure 59
M483A1 projectile transport system

Table 14
Test results summary - inert M483A1 projectiles

Test date	Test no.	Tooling	Munition configuration	Cool down time (min)	Press closure spacing (in.)	Maximum press force	No. of submunition grenades accessed	Comments
3/25/97	1	Shaped	Full-up projectile with 88 submunition grenades	1140	4.96	~750 ~750 ~750	55 of 88	Projectile stuck in upper tooling following first press stroke. Projectile dislodged from upper tooling on third press stroke. Good nose-end and butt-end removal. No accessing of nose-end cavity. Good projo body breakup outside of fiberglass ring. Inadequate projo body breakup inside of fiberglass ring. Projo body ovalized to shape of lower tooling.
3/26/97	2	Shaped	Four row segment with 32 submunition grenades	1140	3.83	~580	23 of 32	Fiberglass ring appeared to inhibit projo body breakup. Test judged to be non-representative due to ejection of grenades from the open ends of the projo body segment during the fracture Projo body ovalized to shape of lower tooling..
3/26/97	3	Shaped	Full-up projectile with 88 submunition grenades - w/o nose ring	1140	4.89	626 686 655 769 672 776	59 of 88	Six press strokes. No hangup in upper tooling. Good nose-end and butt-end removal. No accessing of nose-end cavity. Good projo body breakup outside of fiberglass ring. Inadequate projo body breakup inside of fiberglass ring. Projo body ovalized to shape of lower tooling.
2/26/97	4	Shaped	Seven row segment w/56 submunition grenades	120	4.77	725 753	43 of 56	Two press strokes. No grenades ejected from projo body during fracture. Poor breakup of projo body. Projo body ovalized to shape of lower tooling.
3/27/97	5	Shaped	Empty round w/o nose ring	50	3.91	759	na	Good breakup of projo body. Fiberglass ring tended to hold pieces of body together. Nose cavity accessed. No hangup in upper tooling.
3/27/97	6	Shaped	Full-up round w/88 submunition grenades - w/o fiberglass ring - w/o nose ring	~1080	4.86	787 660 670	62 of 88	Three press strokes. No hangup in upper tooling. Good nose-end and butt-end removal. No accessing of nose-end cavity. Good projo body breakup. Projo body ovalized to shape of lower tooling.

Table 14
(continued)

Test date	Test no.	Tooling	Munition configuration	Cool down time (min)	Press closure spacing (in.)	Maximum press force (tons)	No. of submunition grenades accessed	Comments
3/27/97	7	Shaped	Full-up projectile w/88 submunition grenades - w/o nose ring	50?	4.93	660 684 718	64 of 88	Added two fracture initiators, located on upper tooling perpendicular to axis of projo. Three press strokes. No hangup in upper tooling. Good nose-end and butt-end removal. No accessing of nose-end cavity. No improvement in projo body breakup. Projo body ovalized to shape of lower tooling.
3/27/97	8	Shaped	Projo body w/o nose ring - w/2 rows w/8 submunition grenades per row	60	4.13	~750	9 of 16	Void space filled with foamboard. Butt-end removed for rapid cooling and reinstalled for fracture. Good breakup of projo body. Good nose-end and butt-end removal. Nose-end cavity accessed. Butt-end and piece of projo body wedged in upper tooling.
4/9/97	9	Flat Plate	Two row segment w/16 submunition grenades	235	1.33	720	13 of 16	Grenades held in projo body with foamboard plugs. Excellent projo body breakup, even inside fiberglass ring. Severe crushing of grenade fuze elements. Three unaccessed grenades ejected from the projo body into the frag cart.
4/9/97	10	Flat Plate	Seven row segment w/56 submunition grenades	256	1.89	684	40 of 56	Grenades held in projo body with foamboard plugs. Excellent projo body breakup. Severe crushing of grenade fuze elements. Thirteen unaccessed grenades ejected from the projo body into the frag cart. Three unaccessed grenades on lower tooling.
4/9/97	11	Flat Plate	Full-up projectile w/88 submunition grenades	341	1.56 1.50 1.40 1.40	653 652 699 681	65 of 88	Four press strokes used. Fourteen unaccessed grenades ejected from the projo body into the frag cart. Excellent projo body breakup. Severe crushing of grenade fuze elements. Expulsion charge cavity not accessed.

Tests 1 through 8 used the shaped tooling configuration. Test 1 used a full-up projectile with 88 submunition grenades. When the press slide was raised following the first stroke, the entire projectile, including its nose end and butt end was wedged in the upper tooling. The press was stroked a second time and the entire projectile remained wedged in the upper tooling. The press was stroked a third time and the projectile body and submunition grenades then remained on the lower tooling while the nose end and butt end fell into the fragment cart. Good removal of the nose end and butt end were obtained but insufficient crushing was achieved to access the expulsion charge cavity in the nose end. Good projectile body breakup was obtained in the areas outside the fiberglass ring but the body inside the fiberglass ring was not sufficiently broken up. The projectile body pieces were ovalized to the shape of the lower tooling and gouges in the lower tooling indicated that much of the pressing force was being applied through the projectile body pieces into the tooling, thus preventing further press stroke and limiting the force available to crush the submunition grenades. The press closed only 1.14 in. after contact with the projectile body. Only 55 of the 88 submunition grenades were adequately accessed. It was found that every row and every column contained unaccessed grenades. The observed maximum pressing force for each of the three press strokes was approximately 750 tons. It was concluded that the projectile body wedging in the upper tooling was caused by insufficient distance between the upper tooling end fences. It was recognized that a relatively minor modification of the tooling would eliminate the wedging problem. In order to expedite the testing, it was decided that, instead of modifying the tooling, the nose ring would be removed from the remaining projectiles to prevent the wedging.

For test 2, it was decided to cryofracture a four-row segment of the cylindrical portion of the projectile body containing 32 submunition grenades (eight columns of four grenades). It was hoped that this test would produce greater crushing (due to less material to crush) and this would indicate whether a higher press tonnage might improve the fracture of a full-up projectile. The four-row segment was made up by cutting a 7-in. long cylinder from the projectile body with a bandsaw. Greater munition crushing was obtained. The segment was crushed 2.27 in. following contact with the body. The test was judged to be non-representative, however, because a number of unaccessed submunition grenades were ejected from the open ends of the body cylinder during the fracture. The resulting voids within the body prevented crushing forces from being applied to those grenades remaining in the body. Only 23 of the 32 grenades were adequately accessed. As in test 1, the fiberglass ring appeared to inhibit the breakup of the projectile body and again the partially broken body pieces ovalized to the shape of the lower tooling. The press did not reach its rated capacity for this test. A maximum pressing force of approximately 580 tons was observed on the local press tonnage gage. It is believed that the regulator that was adjusted to obtain full press capacity was sticking (the press had never been used with this regulator adjusted for full capacity). Prior to the next test, the press tonnage regulator was again adjusted with only limited success in repeatedly obtaining the full 750 tons.

Test 3 was a repeat of test 1, but with the projectile nose plug removed. This test was performed to verify that wedging in the upper tooling could be prevented by effectively moving the nose end fence outward. No wedging occurred. A total of six press strokes with pressing loads from 626 to 776 tons were used. Results were similar to those obtained in test 1. Good removal of the nose end and butt end were obtained, but insufficient crushing was achieved to access the expulsion charge cavity in the nose end. Only 59 of the 88 submunition grenades were adequately accessed.

Test 4 was a seven-row segment of a cylindrical portion of a projectile body containing 56 submunition grenades (eight columns of seven grenades). It was hoped that the longer segment (than test 2) would allow at least the inner rows of grenades to remain in place and, with the greater expected crushing of the less than full length projectile, a better assessment of the potential to access all grenades in a given row could be made. Two press strokes were used. The goal of the test was met in that no grenades were ejected from the projectile body during the fracture. The projectile body segment was not adequately broken up and only 43 of the 56 submunition grenades were adequately accessed. This test was particularly revealing in that it showed that even a significantly shortened projectile length could not be adequately cryofractured in the shaped tooling. A 753 ton pressing force was only able to crush the segment 1.33 in. following contact with the segment body. The debris bridging effect and the gouging of the tooling by the projectile body pieces was very evident.

Test 5 was performed to assess the effects of cryofracturing an empty projectile. A 2.19-in. crush was achieved after contact with the projectile body. This was sufficient to access the expulsion charge cavity in the nose end of the projectile. Good butt end removal was obtained.

Test 6 was a repeat of test 3, but with the fiberglass ring removed to allow assessment of the effects of this ring on the breakup of the projectile body. Figure 60 shows the cooled projectile on the press tooling just prior to the fracture. Note the copper press closure spacing specimens on the lower tooling. Figures 61 and 62 show the debris on the tooling after the fracture. The projectile body did show improved breakup in the area where the fiberglass ring would normally reside. Figure 63 shows the cryofractured debris following manual removal of the projectile body pieces. Many apparently unaccessed submunition grenades can be seen. A pressing force of 787 tons was only able to crush the munition 1.74 in. following contact with the projectile body. Figure 64 shows all 88 submunition grenades removed from the projectile body. Only 62 of the 88 grenades were adequately accessed. Good removal of the nose end and butt end were obtained but insufficient crushing was achieved to access the expulsion charge cavity in the nose end.

Test 7 was a repeat of test 3, but with two 0.254-in. thick fracture initiators added to the upper tooling in an effort to improve the breakup of the projectile body, particularly in the area of the fiberglass ring. The fracture initiators were positioned perpendicular to the axis of the projectile. The fracture initiators produced no improvement in the breakup of the projectile body and only 64 of the 88 submunition grenades were adequately accessed. Good removal of the nose end and butt end were obtained but insufficient crushing was achieved to access the expulsion charge cavity in the nose end.

Test 8 cryofractured a projectile loaded with 16 submunition grenades (two rows of eight grenades) positioned in the center of the projectile body and held in place with foamboard plugs on both ends. The purpose of this test was determine if the additional crushing expected, due to using only a partially filled projectile, would result in the accessing of all submunition grenades. Good breakup of the projectile body was achieved and the expulsion charge cavity in the nose end was accessed, but only nine of the 16 submunition grenades were adequately accessed. Examination of the tooling revealed that the projectile butt end and a piece of the body were wedged in the upper tooling. The fracture signature was not recorded for this test, but the local press tonnage gage

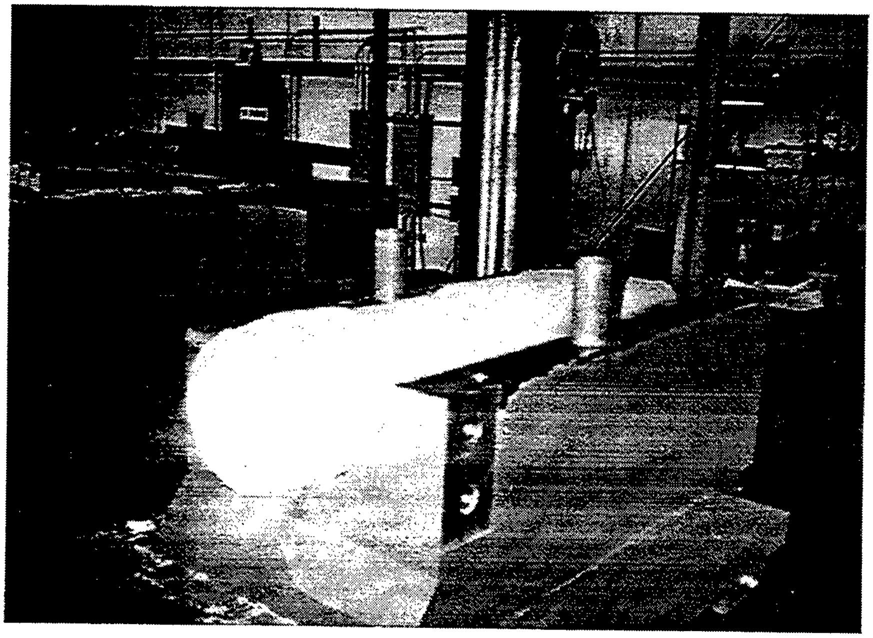


Figure 60
Cryocooled M483A1 projectile prior to cryofracture

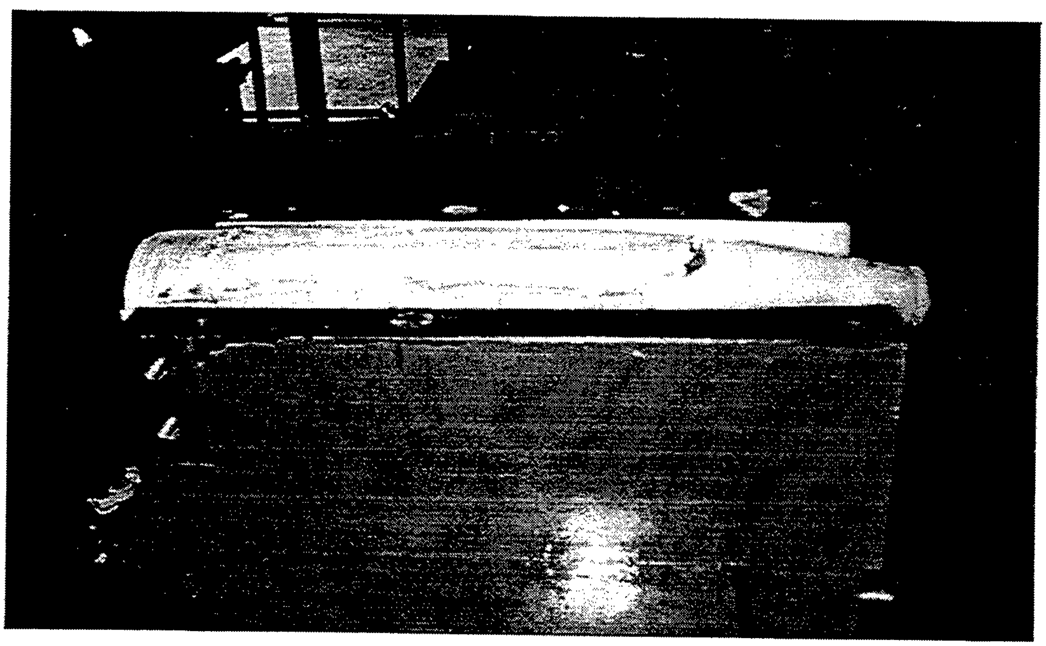


Figure 61
Result of M483A1 projectile cryofracture

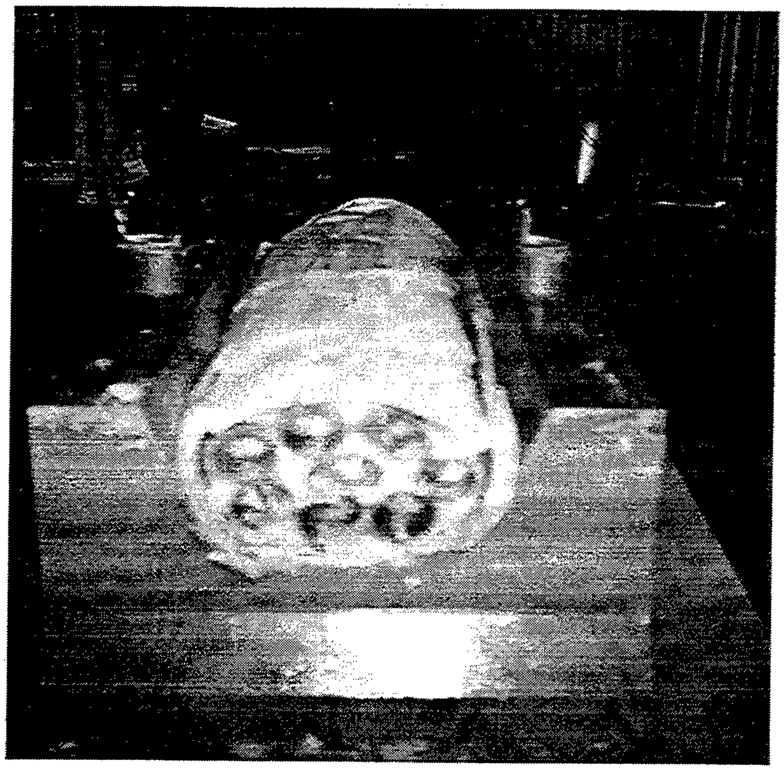


Figure 62
Result of M483A1 projectile cryofracture

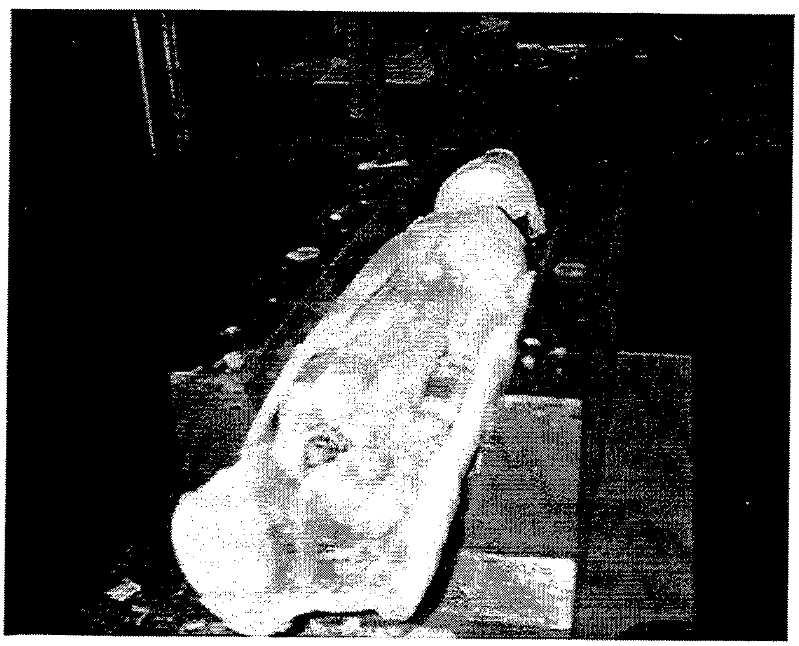


Figure 63
Result of M483A1 projectile cryofracture with top pieces removed

Figure 64
Inert M42/M46 submunition grenade examination

indicated a maximum pressing force of approximately 750 tons. The results of this test provided a good indication that the shaped tooling configuration could not provide the required submunition grenade accessing with a 750 ton pressing force. It was judged that a higher pressing force might provide the required grenade accessing, but it was believed that a significantly higher tonnage would be required.

Tests 9 through 11 used the flat plate tooling that was used for bare submunition grenade and hand grenade cryofracture testing in 1995. Test 9 cryofractured an approximately 13-in. long projectile body segment containing 16 submunition grenades (two rows of eight grenades). The grenades were placed in the center of the projectile body segment and held in place with foamboard plugs at both ends. The cryofracture produced excellent breakup of the projectile body segment. Three unaccessed submunition grenades were ejected from the projectile body (and the tooling) during the fracture. All of the 13 grenades that remained on the tooling were adequately accessed. Some grenades, however, showed severe crushing of the fuze elements. This is a concern for live grenades because the severe crushing could cause the detonators to explode during the fracture. The press closed to a spacing between the flat plates of 1.33 in., a 4.77-in. crush after contact with the projectile body.

Test 10 cryofractured an approximately 18-in. long projectile body segment containing 56 submunition grenades (seven rows of eight grenades). The grenades were placed in the center of the projectile body segment and held in place with foamboard plugs at both ends. Thirteen unaccessed submunition grenades were ejected from the projectile body segment (and the tooling) during the fracture. Three of the 43 grenades that remained on the tooling were not adequately accessed. Some grenades again showed severe crushing of the fuze elements. The press closed to a spacing between the flat plates of 1.89 in., a 4.21-in. crush after contact with the projectile body. Excellent breakup of the projectile body section was obtained. The results of this test provided a good indication that the flat plate tooling configuration could not provide the required submunition grenade accessing with a 750 ton pressing force. It was judged that a higher pressing force might provide the required grenade accessing, but it was believed that a significantly higher tonnage would be required.

Test 11 cryofractured a full-up M483A1 projectile containing 88 submunition grenades. The projectile was positioned on the tooling so that the butt end hung off the end of the lower flat plate. Figure 65 shows the projectile on the press tooling just prior to the fracture. The press closure spacing crush specimens are also shown in figure 65. Figure 66 shows the projectile debris on the tooling following the fracture. The butt end was sheared off the projectile body during the fracture. The nose end of the projectile was broken off and ejected from the tooling during the fracture. The expulsion charge cavity was not accessed. Four press strokes were used in order to obtain maximum crushing. Excellent breakup of the projectile body was obtained. Fourteen unaccessed submunition grenades were ejected from the tooling during the first press stroke. Nine of the 74 grenades that remained on the tooling were not adequately accessed during the four press strokes. On the fourth press stroke the press closed to a spacing between the flat plates of 1.40 in., a 4.70-in. crush after contact with the projectile body. Note that the amount of crushing obtained in this test was greater than in test 10. This is the opposite of what would be expected due to the size of the two test specimens and is an indication of the wide variation in results that can be expected.

It was concluded that additional cryofracture test and tooling development work with a higher capacity press would be required to properly access all the sub-munitions in a M483A1 munition.

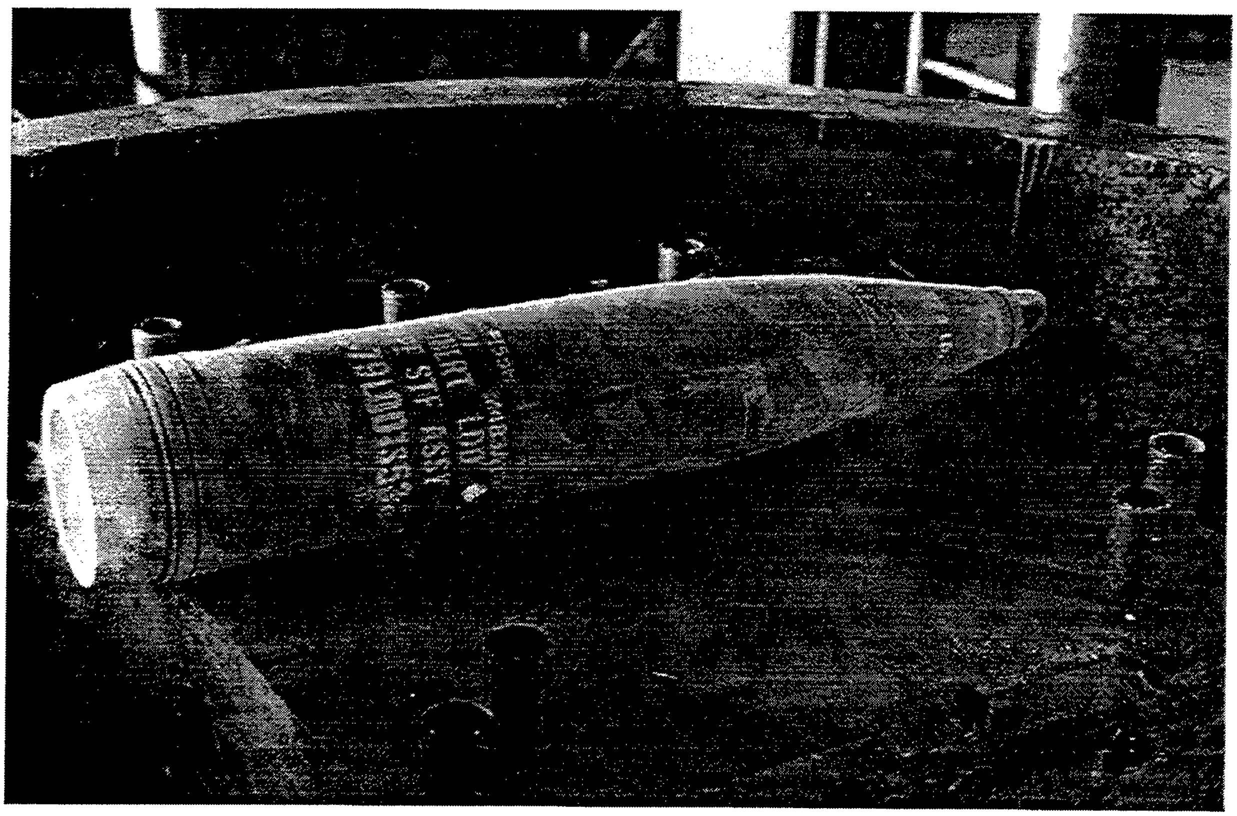


Figure 65
Cryocooled M483A1 projectile prior to cryofracture

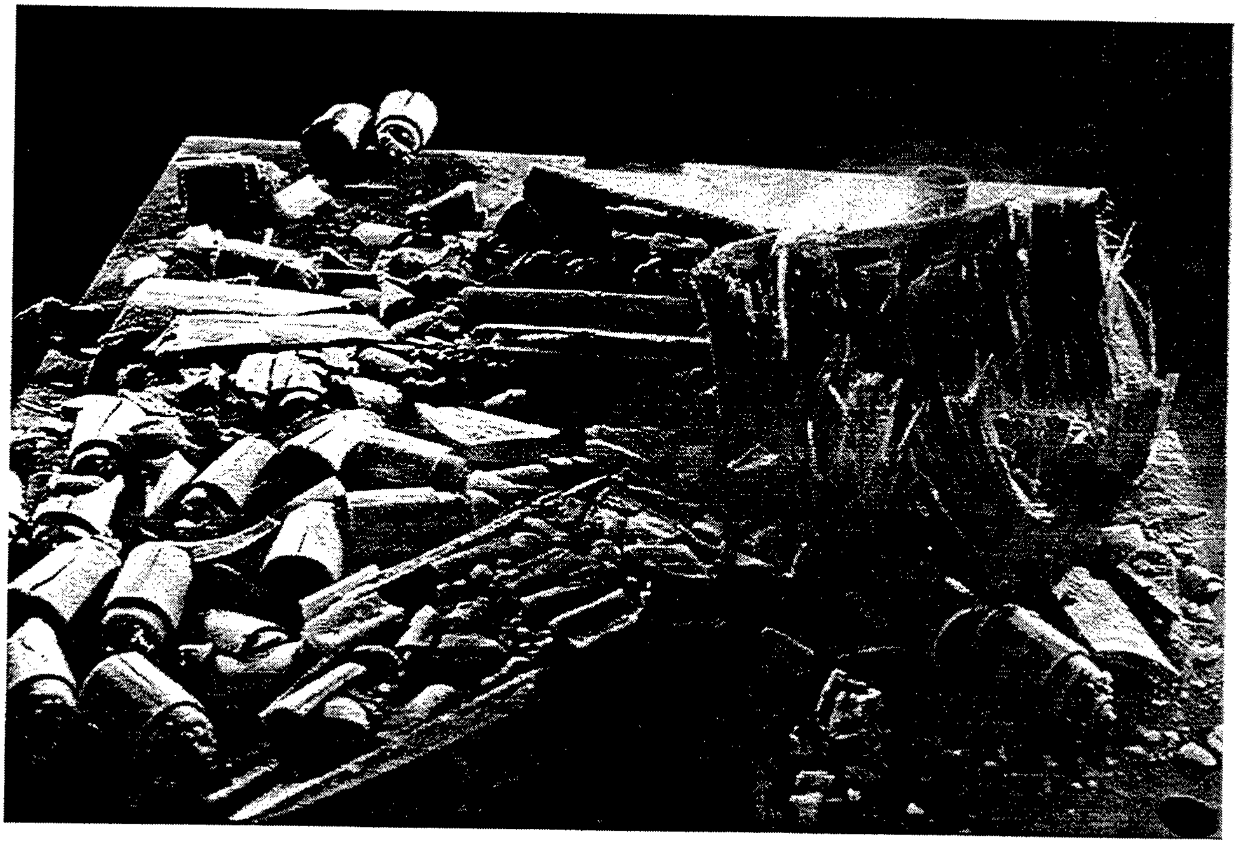


Figure 66
M483A1 projectile debris after cryofracture

PRODUCTION DEMILITARIZATION FACILITY

The cryofracture tests performed on M42/M46/M77 grenades, M67 hand grenades, ADAM mines, Rockeye II AT bomblets, and M16 AP mines demonstrated the feasibility of the cryofracture process for demilitarization of these munitions. The results from these tests are being used as a basis for the ongoing MCAAP MCDF developmental design currently scheduled for completion in the fall of 1999.

Table 15 identifies on a system-by-system basis the parameters determined from this DPG test program for application to the MCAAP MCDF process and equipment.

Table 15
DPG test impacts on MCAAP MCDF

System name	System ID	Parameters determined from WDTC testing
Unpack/Load System	12	Reusable munition transport fixtures with munitions on top of bottom slideable tray with UHMW material for sliding mechanism
Munition Transport System	13	Minimize out-of-cryobath warmup time to less than two minutes
Cryogenic Treatment System	14	Design for 30 minute cool down duration
Press Munition Loader	15	Fixture must not come into contact with press lower tool set to avoid fixture contamination
Cryofracture Press System	16	Upper punch and lower die set for ADAM mine
		Enlarged discharge tubes for O/KM
		Flat plate upper and lower tool set for non-ADAM mines
		50 degree tilt table discharge for debris discharge
		Air flush process with additional lower tool set with verification method (e.g., vision system)
		Provide damping for tilt table motions
Debris Discharge System	17	Two paths for ADAM mines (O/KM and debris)
		One path for non-ADAM mines (Debris only)
		Sand is an effective method to clean out the discharge chutes and the downstream debris handling systems
Debris Separation System - ADAM	18	Separation screen works for O/KM debris removal but requires improved self-cleaning
		Provide dust seals (booting) between components for positive dust control
		Provide a robust vibratory motion for good debris flow
		Orient conveyor to a more horizontal level to slow conveyor debris flow
In-Process Deactivation System - ADAM	19	Screw conveyor for debris transport is preferred method
		Induction heating for energetic deactivation
		GN2 purge to reduce epoxy burning
		Extend length of screw conveyor to allow epoxy to cool prior to entering oxygen environment

Table 15
(continued)

System name	System ID	Parameters determined from WDTC testing
		Screw conveyor and trough material must be made out of high temperature material
		Pulse mode for screw conveyor operation for debris transport
		Screw conveyor cover area surrounded by coil must be high temperature non-metallic cover
Secondary Energetic Accessing - ADAM	21	Lower O/KM accessing tool set should be scalloped
		Minimize press stroke for faster accessing cycle time
		Provide fragmentation shielding
Debris Transport System	24	Shuttle box method of transporting debris
		ADAM O/KM can be discharged and accessed in O/KM accessing press
Positive Feed System	27	Shuttle box must be rapped during APE-1236 RKS dumping to discharge ADAM O/KMs
Dust and Emission Collection	35	Effective dust collection system is required to minimize energetic dust build up
		Good ADAM deactivation emission collection can occur with proper GN2 purge balance
MCAAP APE-1236 RKS	None	Feed in temperature must be high enough to immediately initiate explosive burn but no so high as to cause thermal shock detonation

CONCLUSIONS

Overall

- The Cryofracture process is a feasible, safe means for demilitarization of many types of conventional munitions, particularly those munitions that are difficult to handle and dis-assemble. A prime candidate for cryofracture is the Area Denial Artillery Munition (ADAM) mine.

- Data obtained provided the basis for the design of a production demilitarization facility for M42/M46/M77 grenades, M67 hand grenades, Rockeye II MK 118 bomblets, M16 mines, ADAM mines, and other similar munitions that are difficult to disassemble.

- Multiple munitions can be cryofractured in a single press cycle. However, the number of munitions, and therefore the plant throughput rate, is limited by the feed rate of the subsequent thermal treatment system for the cryofractured debris. This feed rate is, in turn, limited by both safety and permit restrictions.

- The use of reusable munitions transport fixtures for munition handling and press tooling placement was demonstrated to be reliable for production demilitarization operations.

ADAM QA and AP Mines

- The cryofracture process provides an excellent means for accessing the explosives in these mines.
- A cool down duration of 10 min is adequate to provide good brittle fracture.
- A press closure spacing of 0.75 in. provides good explosive accessing without explosions during the fracture.
- Good fractures can be obtained with an out-of-cryobath warm-up duration of up to 2 min.
- Good multiple mine fractures can be obtained with a minimum center-to-center spacing of 6 in.
- The tests demonstrated the capability of fracturing up to six mines at once.
- The ability to punch out and separate primary energetics from other munition components was demonstrated to be reliable for production demilitarization operations.
- The use of punching/separation techniques minimizes the amount of epoxy incinerated.
- The small energetics can be deactivated by induction heat with a residence time of 58 sec.
- The use of induction heating for small energetic deactivation coupled with a gaseous nitrogen purge to minimize the burning of epoxy was demonstrated to be reliable for deactivation operations.

Rockeye II MK 118 AT Bomblets

- The cryofracture process provides an excellent means for accessing the explosives in these bomblets using flat plate crush with horizontally oriented bomblets.
- A cool down duration of 10 min is adequate to provide good brittle fracture.
- A press closure spacing of 1.5 in. provides good explosive accessing without explosions during the fracture.
- Good fractures can be obtained with an out-of-cryobath warm-up duration of up to 2 min.

- Good multiple bomblet fractures can be obtained with side-to-side spacing of 3 in.

- The tests demonstrated the capability of fracturing up to seven bomblets at once.

M16 AP Mines

- The cryofracture process provides an excellent means for accessing the explosives in these mines using flat plate crush with vertically oriented mines.

- A cool down duration of 30 min is adequate to provide good brittle fracture.

- A press closure spacing of 3.25 in. provides good explosive accessing without explosions during the fracture.

- Good fractures can be obtained with an out-of-cryobath warm-up duration of up to 2 min.

- Good multiple mine fractures can be obtained with vertical centerline spacing of 4.0 in.

- The tests demonstrated the capability of fracturing up to three mines at once.

Inert M483A1 155-mm Projectiles

- The reliable and consistent performance of the cryofracture process for demilitarization of M483A1 projectiles containing 88 M42/M46 was not clearly established by the test program.

- Two approaches that could establish the reliability of the cryofracture process were identified. The first approach would be to use a revised press tooling design that would provide improved projectile and bomblet accessing by means of a wider parabolic tool set. The second approach would use a higher tonnage press that would be able to overcome the stalling effects encountered with the 750 ton press at the Dugway Proving Ground Munitions Cryofracture Test Facility site. Both approaches would require demonstration.

RECOMMENDATIONS

- Consider leaving the Munitions Cryofracture Test Facility in place for future development testing of the cryofracture process until the munitions cryofracture demilitarization facility at McAlester Army Ammunition Plant is built and placed into service.

- Investigate the approaches identified from the previous test program [redesigned press tooling (non-flat plate) for improved explosive accessing with less crushing] for establishing cryofracture process reliability for the M61 hand grenade. (GA Report C22288, March 1995).

- Investigate the identified approaches (modify the press tooling and higher press tonnage capability for improved explosive accessing) for establishing cryofracture process reliability for the 155-mm M483A1 projectiles.

- Continue to identify additional munition types that are good candidates for demilitarization cryofracture. Use the Dugway Proving Ground Munitions Cryofracture Test Facility to demonstrate feasibility for new munition types.

- Apply the data developed in this report to the continuous design of the prototype Munitions Cryofracture Demilitarization Facility at McAlester Army Ammunition Plant.

REFERENCES

1. Huntsinger, J.; Betts, P.; and Lute, A., "Cryofracture Demilitarization of Munitions," Contractor Report ARAED-CR-96002, U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ, September 1996.

2. GA Document 219003, Safety Assessment/Preliminary Hazard Analysis - Cryofracture Demilitarization of Munitions.

3. Drawing 029787, Cryofracture Tool Set for M-23 Mines, sheets 1 through 5.

4. Drawing 210002, Upper Insert, Mine Drum Tooling.

5. Drawing 210003, Slide Stop Block, WDTC Press.

6. Drawing 210009, Grenade Handling Basket - Type 1.

7. Drawing 210010, Grenade Handling Basket - Type 2.

8. Drawing 210011, Grenade Handling Basket - Type 3.

9. Drawing 210001, MTR End Effector Arm.

APPENDIX

SUMMARY REPORT, TEAD TESTING

B.1 Introduction

This report summarizes the results of preliminary tests of Area Denial Anti-Personnel Mine (ADAM mine) cryofracture and debris processing equipment in support of the development of the Munition Cryofracture Demilitarization Facility (MCDF). These tests, which were conducted June 15 through 25 and July 13, 1998 at the Tooele Army Depot (TEAD), included evaluations of cryofracture press tooling and debris separation and deactivation equipment. The results of these tests were used to design press tooling and debris processing equipment to be demonstrated in a more thorough series of tests conducted at the Munitions Cryofracture Test Facility (MCTF) at Dugway Proving Ground.

B.2 Summary and Conclusions

A series of ADAM mine demilitarization tests were conducted to evaluate potential techniques for cryofracture accessing and debris processing. Both QA and AP versions of the ADAM mine were used for the tests. Fifteen QA mines were cryofractured to obtain preliminary data on press tooling parameters and crush heights. The data was then used to establish initial conditions for a series of 37 cryofractures of AP mines. The last 30 of the AP mine tests used the same press tooling configuration (punch and die diameters) and the same debris crush height (0.75 in.).

Following the AP mine cryofracture tests, a series of 17 O/KM accessing tests were performed. Thirty-two O/KMs were crushed with flat plate tooling. Up to 6 O/KMs were crushed simultaneously. The results identified that cryocooling/cryofracture coupled with O/KM punchout and subsequent O/KM accessing is an effective means of demilitarizing ADAM mines.

B.3 Test Objectives

The objectives of the tests were as follows:

Cryofracture Tests

- Establish the feasibility of punch and die type press tooling for separation of O/KMs from the mine housings
- Establish the press load required to cryofracture the mine
- Establish press tooling design parameters and crush height
- Determine effects of variation in mine position on the press tooling prior to the fracture
- Establish the minimum allowable mine cool down duration
- Determine the effects of cryocooled mine warmup prior to the fracture
- Characterize the cryofracture debris

O/KM Accessing Tests

- Establish the effectiveness of flat plate crushing for O/KM accessing
- Establish the required press load
- Establish press tooling design parameters
- Determine effects of O/KM warmup prior to crushing
- Determine effects of multiple O/KM crushing
- Characterize crushed O/KM debris

B.4 Test Setup Description and Procedure

All tests were performed at Tooele Army Depot. The cryobath used to cool the ADAM mines was an aluminum pot that was placed in a wood box and surrounded by foam insulation. The pot was filled with liquid nitrogen from a transportable dewar. When filled, the pot was covered with a lid to minimize boiloff. The ADAM mines were loaded into the pot by manual placement in a colander that was then lowered into the pot. The cooled mines were manually removed from the pot and placed on the press tooling. A removable fixture was used to precisely position each mine on the tooling. The press had a capacity of 50 tons and a 13.5 in. stroke. The press was modified to provide additional cylinder and lower tooling mounting beam structural support. A Lexan fragment shield was installed around the tooling. The upper debris discharge chute was used to remove mine housing, S&A, and GG debris from the lower tooling surface. A lower debris discharge chute, mounted just under the upper chute, discharged the O/KM punched through the lower tooling die. Debris was manually scraped off the lower tooling surface and collected in a bucket placed at the bottom of the upper discharge chute. The O/KM and other residual debris were discharged onto a vibrating screening conveyor designed to pass all material except the O/KM. After each fracture, the O/KM and all other debris were manually placed in plastic bags and weighed.

The press tooling was modified for the O/KM accessing tests by replacing the upper tooling cylindrical punch with a 3.4 x 5.0 in. rectangular, flat punch.

B.5 Results

Table B-1 presents a summary of the 15 QA mine cryofracture tests. Cool down durations varied from 22 to 125 min. No effort was made to minimize or otherwise control the cool down duration. Observed press fracture forces varied from 2 to 5 tons. These forces were determined by reading a press mounted tonnage gage on a monitor in the control room. The observed fracture forces were those maximum forces obtained prior to contact of the upper tooling with the lower tooling stop blocks. Due to the rapid transient nature of the fracture, it is possible that the actual fracture forces may be significantly higher than the observed forces.

The S&A was broken up and the GG was exposed for all the QA mine cryofracture tests. The GG remained intact for all tests except Test 12 in which the GG was smashed and it could not be determined if it was accessed.

Test 1 used a debris crush height of 1.0 in. The crush height was reduced to 0.75 in. for Test 2 and then to 0.5 in. for Tests 3 through 12. After observing the smashed GG from Test 12, it was decided to increase the crush height back to 0.75 in. On Test 4, the dummy O/KM hung up in the lower tooling discharge chute and was dislodged with light force.

For Tests 9 through 12, the mine was intentionally mispositioned on the lower press tooling prior to the fracture in order to simulate expected variations due to WDTC and MCDF robot and mine transport fixture tolerances. The mispositioning did not affect the cryofracture results.

On Tests 10 and 14, pieces of mine housing were found on the lower press tooling crush height stop blocks after the fracture. Since this debris might prevent the press tooling from reaching the desired crush height, it will be necessary to design the WDTC and MCDF press tooling so as to prevent cryofracture debris from fouling the stop blocks.

TABLE B-1

RESULTS SUMMARY - QA MINE CRYOFRACTURE TESTS

Test No.	Cool down Time, min	Observed Fracture Force, tons	GG Accessed?	Crush Height, in.	Comments
1	22	3	no	1.0	
2	42	3	no	0.75	
3	60	3	no	0.5	
4	96	unk	no	0.5	O/KM hung up in discharge chute, dislodged with light force
5	54	3	no	0.5	
6	82	2	no	0.5	
7	108	unk	no	0.5	
8	121	2	no	0.5	
9	28	3	no	0.5	0.06 in. side offset
10	101	5	no	0.5	0.13 in. side offset, housing debris on stop blocks
11	44	4	no	0.5	0.13 in. offset - S&A away from punch
12	63	4	unk	0.5	0.13 in. offset - S&A towards punch, GG smashed
13	88	6	no	0.75	
14	110	5	no	0.75	housing debris on stop blocks
15	125	5	no	0.75	

S&A broken up for all tests

GG exposed for all tests

All QA mine tests used an upper tooling punch diameter of 1.56 in. Tests 1 through 3 used a lower tooling die diameter of 1.58 in. The close tolerance between the punch and die produced significant wear on both the punch and die. This may have been due to the looseness of the upper tooling in the press frame. After Test 3, it was decided to increase the lower tooling die diameter to 1.75 in. This die diameter was selected because it was the same diameter as the mine housing epoxy plug and it was reasoned that this would facilitate the punch-out of the O/KM from the housing. The larger die diameter was also expected to reduce the tooling wear seen in Tests 1 through 3. The 1.75 in. die diameter was used for all remaining QA mine cryofracture tests. Tooling wear was significantly reduced from that seen in Tests 1 through 3.

Tables B-2 and B-3 present summaries of the 37 AP mine cryofracture tests. Table B-2 is for Tests 16 through 22. These tests used a crush height of 0.75 in., an upper tooling punch diameter of 1.56 in., and a lower tooling die diameter of 1.75 in. Cool down durations varied from 46 to 193 min. No effort was made to minimize or otherwise control the cool down duration. Observed press fracture forces varied from 6 to 7 tons.

The O/KM was successfully separated from the mine housing for Tests 16 through 22. The kill mechanism remained intact for all these tests. The overlay was ruptured for all of these tests except Test 20. The S&A was broken up for all tests. This debris is typical of what was produced in all the tests. The broken up S&A was clearly visible. The GG was exposed for all tests except Test 22 where the GG remained imbedded in epoxy housing material. For Test 21, the GG functioned when the press was at the bottom of its stroke. There was no evidence of any other energetics involvement.

Tests 17 through 22 all had a significant quantity of housing epoxy material attached to the separated O/KM. The ruptured overlay was clearly seen. On Tests 20 and 22, the O/KM hung up in the lower tooling discharge chute. Both O/KMs were dislodged with light force. After Test 22, it was decided to remove the lower tooling from the press and machine the O/KM discharge chute to increase its diameter from 2.0 to 2.5 in. in order to improve O/KM discharge.

TABLE B-2

RESULTS SUMMARY - AP MINE CRYOFRACTURE TESTS

Test No.	Cool down Time, min	Observed Fracture Force, tons	Overlay Ruptured?	GG Accessed?	GG Exposed?	Wt of Epoxy Attached to O/KM, lb	% of Total Epoxy Attached to O/KM	Comments
16	46	6	yes	no	yes	0	0	Det cord initiator smashed
17	69	6	yes	no	yes	0.040	9.2	
18	178	6	yes	no	yes	0.060	13.8	
19	108	7	yes	no	yes	0.039	9.0	Housing debris on stop blocks
20	141	6	no	no	yes	0.088	20.2	O/KM hung up in discharge chute, dislodged with light force
21	168	6	yes	functioned	yes	0.077	17.7	GG functioned at bottom of press stroke
22	193	6	yes	no	no	0.056	12	O/KM hung up in discharge chute, dislodged with light force

Crush height 0.75 in. for all tests

S&A broken up for all tests

Kill mechanism not ruptured for all tests

1.56 inch diameter punch with 1.75 inch diameter die

TABLE B-3
RESULTS SUMMARY - AP MINE CRYOFRACTURE TESTS

Test No.	Cool down Time, min	Observed Fracture Force, tons	GG Accessed?	GG Exposed?	Wt of Epoxy Attached to O/KM, lb	% of Total Epoxy Attached to O/KM	Comments
23	57	7	no	yes	0.015	3.5	O/KM discharge chute dia increased from 2.0 to 2.5 in. before test
24	80	7	no	no	0	0	
25	102	7	no	yes	0	0	
26	118	7	no	yes	0	0	
27	36	6	no	yes	0	0	Punch bent due to contact with die. Punch replaced
28	227	7	no	yes	0.005	1.2	
29	251	6	no	yes	0	0	
30	265	7	no	yes	0	0	
31	111	7	no	yes	0.033	7.6	
32	137	5	no	partially	0.013	3.0	
33	81	7	no	yes	0.026	6.0	0.13 in. side offset
34	105	unk	no	yes	0	0	0.13 in. offset - S&A away from punch, O/KM hung up in discharge chute, dislodged with light force
35	119	6	unk	unk	0	0	0.13 in. offset - S&A toward punch
36	138	7	unk	unk	0.017	3.9	
37	170	n/a	unk	not found	0	0	Most of broken up O/KM remained on die
38	250	n/a	no	yes	0	0	
39	212	n/a	no	yes	0	0	
40	238	n/a	no	yes	0	0	GG slightly smashed
41	252	n/a	no	no	0	0	
42	270	n/a	no	yes	0	0	
43	17	n/a	no	no	0.012	2.8	
44	27	n/a	functioned	yes	0	0	GG functioned at bottom of press stroke
45	51	n/a	no	partially	0	0	
46	67	n/a	no	yes	0	0	
47	12	n/a	no	partially	0.011	2.5	
48	10	n/a	no	yes	0	0	
49	22	n/a	no	yes	0	0	
50	43	n/a	no	yes	0	0	
51	62	n/a	no	no	0	0	
52	76	n/a	no	yes	0.005	1.2	

Crush height 1.0 in. for Tests 23 and 24, 0.75 in. for Tests 25 through 52
Kill mechanism ruptured for Test 37 only
Overlay ruptured for all tests except Tests 28 and 45
S&A broken up for all tests except Test 37
Average weight of epoxy attached to O/KMs in 30 tests - 0.0046 lb (1.06% of total epoxy weight)
1.34 Inch punch diameter with 1.75 inch die diameter

After Test 22, it was also decided to reduce the diameter of both the upper tooling punch and the lower tooling die. It was reasoned that a smaller diameter die might improve epoxy material removal from the O/KMs.

Tests 23 through 52, summarized in Table 5-3, all used an upper tooling punch diameter of 1.34 in. and a lower tooling die diameter of 1.75 in. A debris crush height of 1.0 in. was used for Tests 23 and 24. Test 24 produced less than desired housing breakup and it was decided to reduce the crush height to 0.75 in. for all remaining tests. Cool down durations for Tests 23 through 52 varied from 10 to 265 min. No effort was made to control the cool down duration except for Tests 47 and 48, which used 12 and 10 min. cool down durations, respectively. Observed press forces for Tests 23 through 52 varied from 5 to7 tons. Press forces were no longer recorded after Test 36 (the CCTV system was needed for other tests).

The O/KM was successfully separated from the mine housing for all Tests 23 through 52 except Test 37. In this test, the O/KM was broken up during the fracture. Most of the broken O/KM debris remained on the lower tooling. The kill mechanism detonator, pieces of kill mechanism body, and primary explosive powder could be seen.

The overlay was ruptured in all except two of Tests 23 through 52. The severity of rupturing was generally greater than seen with the larger lower tooling die diameter used in Tests 16 through 22. Half of the overlay was removed during the fracture.

The S&A was broken up for all but one of Tests 23 through 52. On Test 37, the S&A remained buried in a piece of epoxy. For Test 44, the GG functioned when the press was at the bottom of its stroke. There was no evidence of any other energetics involvement.

The quantity of housing epoxy material remaining attached to the O/KMs after the fracture was significantly reduced by the smaller lower tooling die diameter used in Tests 23 through 52. Twenty-one of these tests had no epoxy attached to the O/KM. The average quantity of epoxy material remaining attached to the O/KMs during Tests 23 through 52 was 1.06 percent.

Tests 33 through 35 intentionally mispositioned the mine on the tooling prior to the fracture. The mispositioning did not appear to affect the cryofracture. On Test 34, the O/KM hung up in the lower tooling discharge chute and was dislodged with light force.

O/KM Accessing Tests

Table B-4 presents a summary of the results of the accessing tests. Thirty-two O/KMs were crushed in a series of 15 tests. Up to six O/KMs were crushed at-a-time. Tests 53 through 59, 62, and 63 crushed single O/KMs positioned in known orientations. Tests 60 and 61 crushed two O/KMs in known orientations. Tests 64 and 65 crushed four randomly oriented O/KMs and Tests 67 and 68 crushed six randomly oriented O/KMs. Crush heights were varied from 0.875 to 1.125 in. The propellant nut/detonator column was positioned horizontally for Test 53. This orientation always produced better accessing than a vertical orientation of the propellant nut/detonator column.

Test 56 used a crush height of 0.875 in., the smallest crush height tested. The small crush height and the vertically oriented prop nut/detonator column led to a detonation at the bottom of the press stroke. Other than a slight bowing of the sides of the O/KM container, the detonation produced no damage. It could not be determined which explosive element(s) was involved in the detonation. The explosive elements in the detonator column did not appear to have functioned. Primary explosive was found in the O/KM container and outside the container on the press tooling surfaces.

Both Test 60 and 61 produced excellent accessing. Tests 62 and 63 crushed ambient temperature O/KMs. The horizontally oriented O/KM was well accessed. The vertically oriented O/KM in Test 63 was not accessed. The O/KM simply flattened on the top and the bottom, and no separation of the kill mechanism half shells was achieved.

Three of the four O/KMs were well accessed in Test 64 and the fourth was marginally accessed. Test 65 was a repeat of Test 64. In this test, a small pop occurred at the bottom of the press stroke. The pop was judged to be produced by the functioning of a portion of det cord.

TABLE B-4

RESULTS SUMMARY - O/KM ACCESSING TESTS

Test No.	No. of O/KMs	Pre-Fracture O/KM Orientation	Crush Height, in.	Observed Fracture Force, tons	Results
53	1	prop nut on side	1.125	N/a	Excellent accessing
54	1	prop nut on side	1.0	N/a	Excellent accessing
55	1	prop nut up	1.0	N/a	Good accessing
56	1	prop nut up	0.875	n/a	Moderate pop at bottom of press stroke. Container sides slightly bowed out.
57	1	prop nut up	1.0	5	Excellent accessing
58	1	prop nut up	1.125	9	No visible accessing
59	1	prop nut up	1.0	5	Recooled O/KM from Test 58. Marginal accessing
60	2	prop nut up	1.0	12	Good to excellent accessing
61	2	prop nut on side	1.0	n/a	Excellent accessing
62	1	prop nut on side	1.0	3	Uncooled O/KM. Excellent accessing
63	1	prop nut up	1.0	n/a	Uncooled O/KM. No accessing
64	4	random	1.0	10	All O/KMs accessed, one marginal
65	4	random	1.0	15	Excellent accessing in all O/KMs. Small pop at bottom of press stroke. Judged to be piece of det cord.
67	6	random	1.0	unk	Excellent accessing in all O/KMs. Small pop at bottom of press stroke in a prop nut down O/KM.
68	6	random	1.125	unk	One O/KM not accessed

O/KM(s) cooled to dead cold for all tests except Tests 62 and 63

All six O/KMs were well accessed in Test 67. A pop at the bottom of the press stroke was in an O/KM that was oriented with the detonator column vertical and the propellant nut down. Test 68 was a repeat of Test 67, but with a 1.125 in. crush height. One of the six O/KMs was not accessed.

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